THE IMPACT OF REDUCED MANNING ON NAVAL SHIPS

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by

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ABSTRACT

The impact of various manning levels aboard Naval escort type ships was examined. A constant level of ship performance was attempted through changes in equipment and procedures. The impact of various combinations of men and equipment on ship design and acquisition cost was evaluated using a ship synthesis model. The cost of crew, fuel, and added shore support required because of reduced manning was determined for each manning level. These costs were combined with acquisition cost to produce a modified life cycle cost. The performance of each ship developed in the study was evaluated on a subjective basis. By combining the results of life cycle cost and ship performance, conclusions were drawn about the optimum manning level aboard the next generation of Naval escorts.

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CHAPTER 1

INTRODUCTION

Prior to the 1970's the cost of manpower had been a comparatively small part of the Navy's annual budget. In the early 1970's the draft was ended and Congress made an attempt to make military pay equivalent to civilian pay. This pay increase had a dramatic impact on the Navy's budget. By 1975 manpower cost was an estimated 65% of the budget, and 55% of the Life Cycle Cost (LCC) of an average ship. (1) (NOTE: Numbers refer to references at the end of this thesis.)

Besides the high cost of manpower, there are a number of other compelling reasons to lower the crew size on Naval ships. In an address to the American Society of Naval Engineers on 3 May 1974, Vice Admiral W. D. Gaddis stressed the fact that in the future the supply of skilled people will be limited. A 500,000 man Navy has been selected for planning purposes because that is the maximum force level set forth by law in a non-emergency environment. According to the Bureau of Labor Statistics, there will be a decline of approximately 2.2 million males in the 18-24 age group during the 1980's. The elimination of the draft, the base force limit of 500,000, and the decline in the number of men in the prime service age group make it important for the Navy to search for ways of utilizing it's manpower as efficiently as possible. (2)

The impact of the crew on ship size and cost is an important consideration. A large crew requires either a larger more expensive ship or a smaller payload.

A final reason in support of smaller crews on warships is to reduce loss of life in combat. Warships, by their very definition, will go in harms way and some will be damaged or lost. To expose any more people than necessary is a waste of life.

1.1 Survey of Past Results

Two noteworthy papers have been published which examine the requirement for and the effects of reduced shipboard manning.

Reference 3 developes a combat system for two Frigate Hydrofoils (FFH):

> FFH 83 uses existing equipment and has a crew of 78.
>
> FFH 90 uses equipment under development and has a crew of 55.

Both ships were multimission with high-firepower in that they carried:

- Antiaircraft Missiles
- Antiship Missiles
- Towed Array Sonar
- Antisubmarine Torpedoes

The low manning level was achieved by use of:

Highly integrated command and control (C&C) and weapons control system

Aircraft type ship control

Gas turbine propulsion plant

Reduced maintenance due to built-in-test, increased reliability, and redundancy in key areas

Strong shore support

Large billet cost savings were possible over conventional ships with the same mission. Comparison of crew cost with two more conventionally manned frigates in 1974 dollars are shown below:

FFG 1	$4,622,589/year
FFG 7	3,442,276
FFH 83	1,594,347
FFH 90	1,197,693

A final conclusion of reference 3 was that a ship like FFH 83 is feasible in the 1980's.

References 4 and 5 examined four manning alternatives for escort type ships with crews ranging from 62 to 21 men. They investigated the feasibility of significant changes which can at the same time reduce manning and improve military capability.

Using the FF 1052 as a design point, reference 4 indicates that the impact of the crew aboard a small surface combatant is 5 tons/man and 600 ft^3/man. These figures were for the FF 1052 assuming that propulsion and weapons systems were held constant.

One of the key results of reference 4 was an awakening to the price of support personnel. The FFG 7 has 50% fewer watchstanders when compared to the FF 1052, but there is not a similar reduction in the number of support personnel. In addition to no reduction in the equipment maintenance load, the FFG 7 has the same requirements for, and system of, accomplishing it's support functions. A final conclusion was that the most desirable means of achieving a reduction in manning requirements is through the outright elimination of duties, functions, equipment maintenance or other requirements.

Other studies have covered small parts of the overall manning problem, most notably in the area of ship control. Reference 1 deals with bridge manning. The conclusions of this study were:

> Ship control has changed little in 50 years.
>
> A 50% reduction in bridge personnel with little or no equipment change is possible.
>
> Modest equipment changes can reduce the required personnel to an officer of the deck and a ship control console operator.
>
> Tradition is the largest single obstacle to reduction of bridge watch personnel.

References 8 through 10 are a series of reports by the Naval Sea Systems Command on the subject of ship manning. This series contained surveys of ongoing developments which will have an impact on ship manning, such as, new materials, new weapons systems, and changes in procedure. They were also

intended to spark interest in, and discussion of reduced manning throughout the Navy. Further research and development was urged in the areas of:

Equipment reliability and availability

Automation of shipboard functions

Ship rearrangement to promote efficiency

Doctrinal changes

1.2 Present Trends in Manning Aboard U.S. Naval Ships

Beginning in 1960 a new method of manning prediction started to replace the old system based on experience and rules of thumb. (6 and 7) This was because the old system had resulted in large errors in the prediction of the crews required for various Naval ships. At the same time, it was also felt that a greater design effort was required to integrate men into the total ship system. A modified British work study process was adopted for the U.S. Navy. Unlike the British system, the American system is applied during the design phase. The name "Design Work Study" (DWS) was chosen to identify this process. Essentially, DWS consists of a synthesis of method study, work measurement, and industrial engineering techniques adapted for management use. The final goal of the DWS process is the achievement of the most economical and efficient combination of payload, support subsystems, and manpower that will allow the new design to accomplish it's assigned mission.

Since it's inception, DWS has been applied to the DD 963,

FFG 7, CVAN 68, DLGN 38, and AO 177 plus a number of designs which did not go to the contract phase. The manning reductions on these ships range from 19% for the DLGN 38 as compared to the DLGN 36, to 55% for the AO 177 as compared to the AO 105. However, it should be noted that this reduction is only partly due to DWS. The major part of these manning reductions was due to changes in mission or technology and would have occurred whether or not the DWS discipline had been initiated.

The trend to reduced manning in the latest design in each class of surface combatant ships is clear in Figure 1. The same information is shown in Figure 2 normalized in terms of men per kiloton full load displacement. Here a steady trend toward fewer men per ton can be seen over the past thirty years. There are two reasons for this trend. Figure 2 shows that the larger ships tend to have fewer crew members per ton, thus the trend to increased displacement in post World War II ships reduces the crew member to displacement ratio. The second reason for the decreasing crew to displacement ratio is a greater effort to reduce manning and increase automation.

More specifically, this manning reduction is due to the application of some or all of the following items to the more recent ship designs.

The use of gas turbine in place of manual control steam plant

Integrated digital combat systems in place of manual analog systems

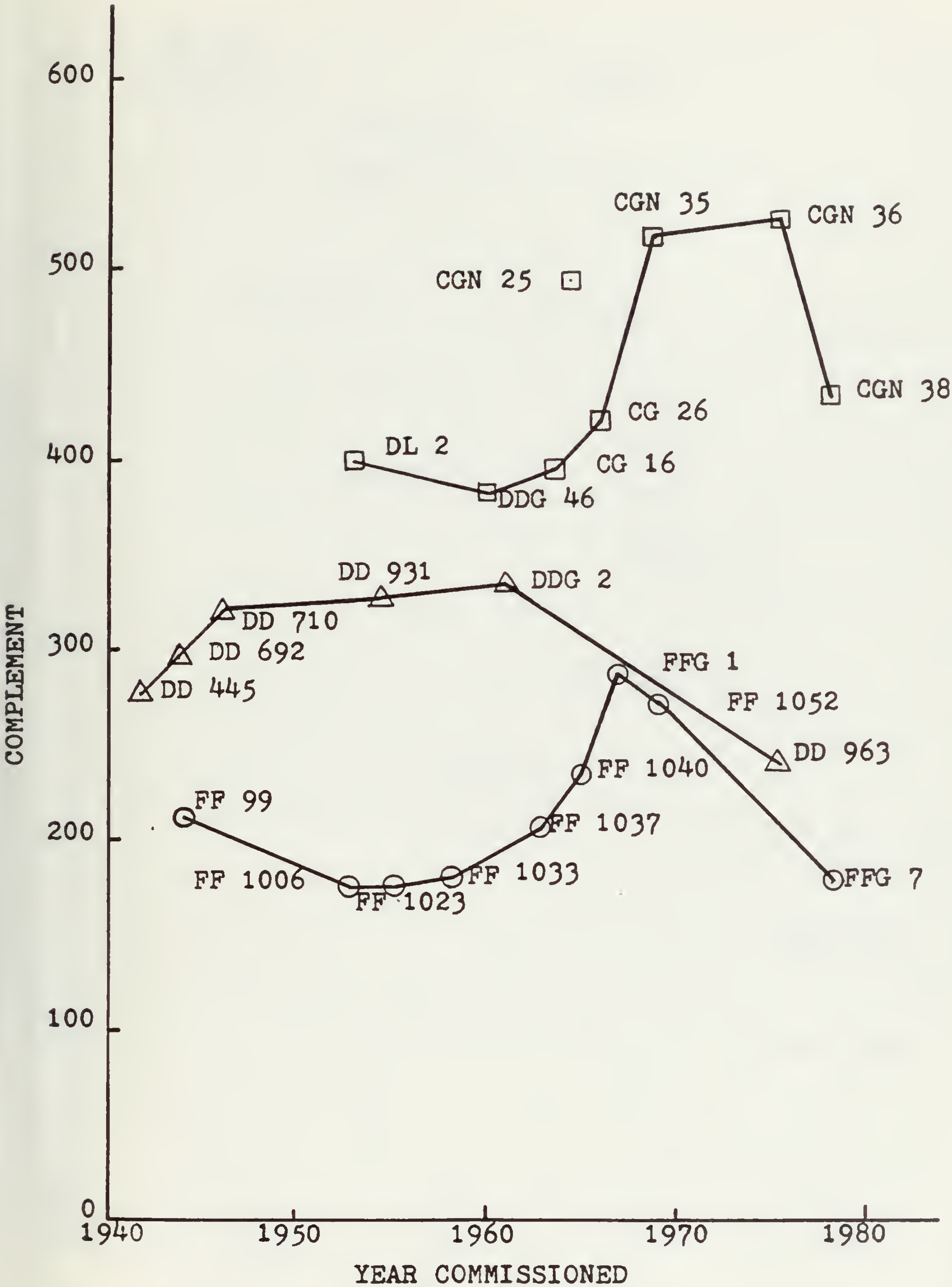

Figure 1. Crew Size Trends in Destroyer Type Ships (16)

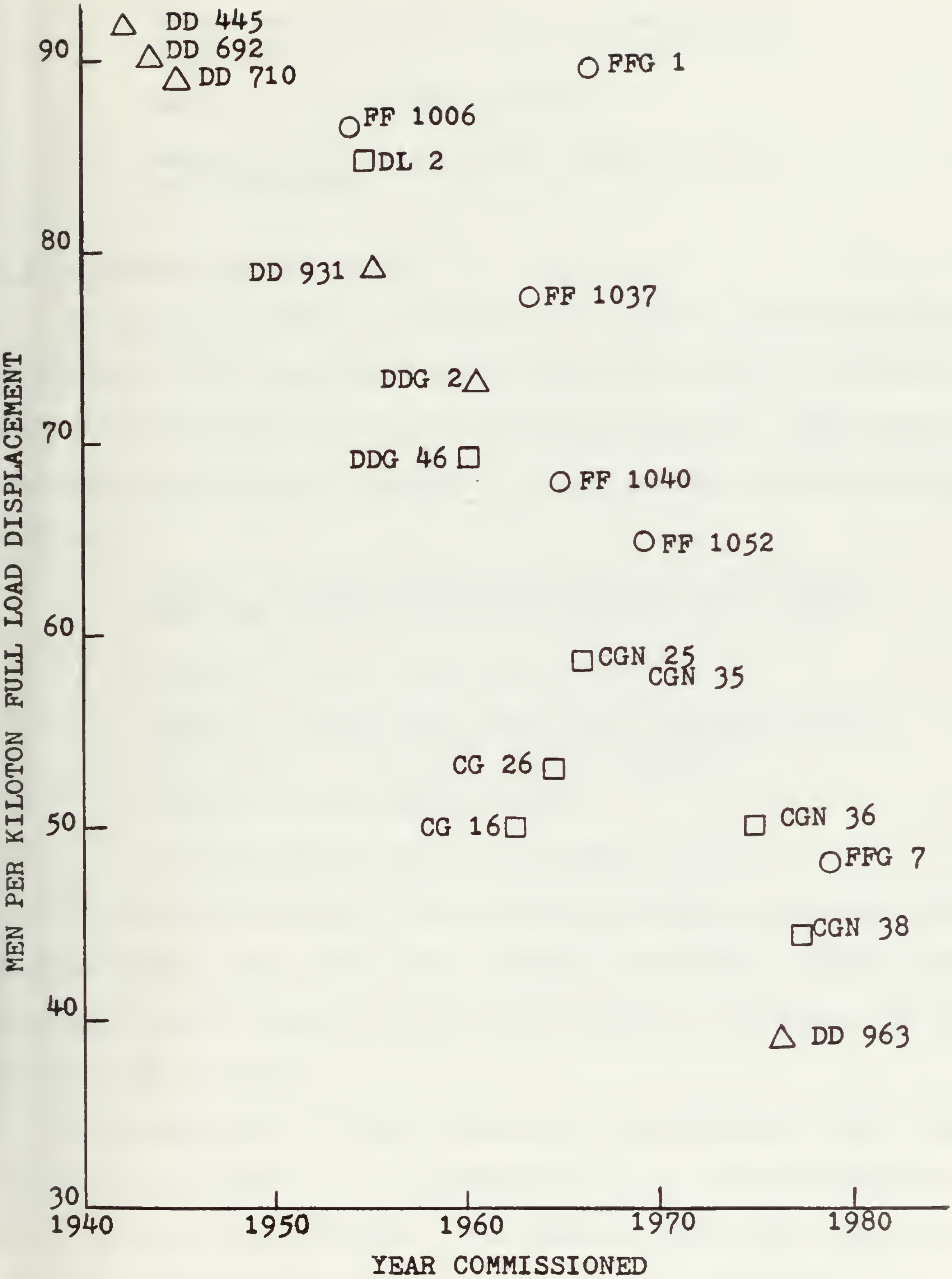

Figure 2. Trend in Ship Manning per Kiloton of Full Load Displacement

Mechanization of missile and ammunition handling

Reduction in bridge manning

Aircraft type maintenance approach for some equipment

1.3 Scope of Present Work

In general, previous studies have shown that crew cost can be reduced with automation and procedural changes, and that much smaller ship's crews are possible by 1990. They have not covered in any depth a number of other aspects of the problem, such as:

Impact on ship size when equipment to support the low manning level is added to the ship

Impact on ship acquisition cost

Impact on ship life cycle cost, particularly the cost of increased shore support

Impact of ship performance

Impact on the Navy's personnel system

In addition, most of the previous studies have had only limited scope, while the more complete ones have passed over the near term in favor of more long range solutions, with crew sizes of 80 or less.

The main goal of this thesis was to determine what combination of personnel and equipment would be the most effective for a typical ocean escort. The thesis deals with near term, the type of ship that could go into design today with low risk systems and a mid-range of crew sizes (80-200). The Navy is

unlikely to build a ship with less than 80 people before it has built a number of ships with 80 to 200 people. The FFG 7 with a crew of 182 is the first step in this direction. It is important to note that this ship and the DD 963 and AO 177 are under attack within the Navy because of their small crews. Several more years of experience will be needed to evaluate these ships which are the first of the ships with reduced manning.

The analysis was carried out in the following five steps.

1. Eight manning options and ships were developed for a typical ocean escort mission.

2. The impact on size and acquisition cost of each option was determined.

3. A modified life cycle cost was determined.

4. The performance of each option was evaluated.

5. The impact of reduced shipboard manning on the Navy's personnel system was evaluated.

CHAPTER 2

ANALYTICAL APPROACH

The details of the analytical approach are covered in this chapter. A summary of the method is given below.

1. Manning and Equipment Options

   Eight manning and equipment options were developed starting with a conventional manned ship with a typical ocean escort mission. The crew size was varied from 276 to 70 men, while equipment and procedures were changed to keep performance as constant as possible.

2. Ship Impact

   The size and cost of each of the eight ships were determined using a ship synthesis model.

3. Life Cycle Cost (LCC)

   The ship acquisition cost from the synthesis model was combined with the following elements of LCC to give a modified life cycle cost.

   Thirty year crew cost
   Thirty year fuel cost
   Cost of extra shore support required for ships with low manning

   Elements of LCC which would be constant for any crew size were not evaluated.

4. Ship Performance

   The performance of each ship was evaluated using the conventionally manned ship as a baseline.

5. Other Impact of Reduced Manning

   The smaller, highly skilled crews of ships with low manning, combined with the need for shore support will require changes in the Navy's personnel system. These are examined briefly in the final section.

2.1 The Manning and Equipment Model

The ships in this study were to be capable of performing the functions of a typical ocean escort. These functions require capabilities in three major warfare areas.

Antiair Warfare (AAW)

Antisubmarine Warfare (ASW)

Surface Warfare (SUW)

In addition to these combat functions, certain support services must be provided, such as:

Medical services

Commissary and other human support services

Maintenance of equipment

Administrative functions

An improved FF 1052 was chosen as the base ship because it has the features listed above. In addition, it was the last ship to be constructed with little attention to reducing crew size. This allowed a wide range of crew sizes to be studied. The FF 1052 used in this study was assumed to have the following changes to the equipment it had at commissioning.

Manned helicopter in place of a drone

Basic Point Defense Missile System installed

Harpoon antiship missile installed

MK-48 torpedo system removed

A more detailed list of the functions and capabilities assumed for the escorts is shown in Table 1 in the form of a

TABLE 1

REQUIRED OPERATIONAL CAPABILITIES

Antiair Warfare

Detect aircraft at long and short range

Engage aircraft with five-inch gun

Engage aircraft with missiles at short range

Control aircraft

Antisubmarine Warfare

Detect submarines at long and short range

Engage submarines at long and short range with conventional weapons

Use own helicopter in antisubmarine warfare role

Surface Warfare

Detect surface contacts

Engage surface contacts with gun

Engage surface contacts with missiles

Conduct electronic warfare

Conduct Naval gun fire support

Use own helicopter in surface warfare role

Mobility

Steam at full power

Repair propulsion and auxiliary systems

Control damage

Maintain damage security

TABLE 1 (continued)

Special Warfare

Surveillance and reconnaissance

Visit, search, and prize crew

Command and Control

Communicate by visual and electronic means

Process message traffic

Function as antisubmarine warfare control ship

Noncombat Operations

Man overboard

Medical care

Administration and supply support

Repair own equipment

Fleet Salvage Operations

Salvage

Rescue

Sea Detail

Enter and leave port

Refuel and rearm underway

ROC (Required Operational Capabilities). These functions and capabilities were held constant where possible on each of the ships with different manning options. Any changes in performance of the functions on this list will be discussed in the section on ship performance.

Crew size determination was the first step. The Navy uses the DWS method which was discussed briefly in the introduction. A part of this system is the Manpower Determination Model computer program. (7) It has a data base made up of the manning required for various systems and subsystems that are found aboard Naval ships. The program uses this data base in addition to information such as work week and nonequipment related work load. After insuring optimum cross-utilization of personnel, a document similar to a Watch, Quarter, and Station Bill is produced. At present, this model is only applicable to conventional manning determination. A data bank for more austere manning, such as found on the FFG 7, is under development, but is not fully completed. Even if it was available, it would not be applicable to the ships at the low manning end of this study. Because of this, another method of manning determination had to be used.

The manning document for the FF 1052 (11) serves as a starting point in developing the various manning options. From that point the crew size was reduced and equipment and operating doctrine changed to allow the smaller crew to perform the

functions in Table 1. At sea watch stations (Operational Manning) during Condition III were the predominant factors in selecting crew size.

Eight ships were developed in the study counting the modified FF 1052. For the purpose of easy identification, the ships were numbered 1 through 8 starting with the FF 1052. The crew selections for ships 2 and 3 were made using references 12 through 14 as guides to operational manning. These references represent the most current developments in shipboard manning. Ships 4 through 8 have operational manning and equipment similar to FFH 83 in reference 3. In general, references 3 and 12 through 14 could be used for equipment selection and operational manning, but did not cover all aspects of the required manning.

The other types of manning are shown below. (15)

> Maintenance Manning, which can in turn be broken down into three types.
>
> > Preventive maintenance, or that maintenance required to prevent failure of equipment.
> >
> > Corrective maintenance, or that maintenance required to restore to service failed equipment.
> >
> > Facility maintenance, which is the normal cleaning and painting required to keep the ship livable and attractive.
>
> Administrative and Support Manning, which is the manning required to perform ship's office, medical, supply and commissary functions.
>
> Utility Manning, which is the miscellaneous

work that is required, but does not fall into any of the above categories. The largest item in this group is special details such as Sea and Anchor.

The FF 1052 Manning Document contains detailed information on the required hours of each type of manning listed above. The Manning Document also details how the required work is assigned to the crew members. For the purpose of crew size selection in this study, the level of detail in the manning was not required. It was adequate to divide the types of manning listed above into categories that are dependent on crew size, ship size, and shipboard equipment. Each category was adjusted appropriately as the ships in the study were developed. The division is shown below.

Crew Size

Commissary services
Medical support
Personnel and pay record functions
Interior facilities maintenance

Ship Size

Hull maintenance (Exterior facilities maintenance)

Shipboard Equipment

Maintenance of weapons, electronics, and machinery

All the functions shown above were easy to categorize except facilities maintenance. After discussions with the Naval Ship Engineering Center's DWS group, facilities maintenance was divided into its exterior and interior components. The exterior component is predominately a function of deck area,

which for ships of similar shape is a function of the square of ship length. The relation shown below was used to calculate the required exterior facilities maintenance.

$$HFM1 \times (L_n/L_1)^2 = HFM_n$$

Where: $HFM1$ = 332 hr/week, the hours of exterior facilities maintenance required aboard the modified FF 1052 (Ship 1)

L_1 = Length of ship 1

L_n = Length of ship n

HFM_n = hours of exterior facilities maintenance required aboard ship n

Interior facilities maintenance was assumed to be a direct function of crew size. The hours of interior facilities maintenance required aboard ship 1 (886 hr/week) were changed in proportion to crew size changes to obtain an estimate for the other ships in the study. Both of the assumptions above have a small error, however the results were accurate enough for the purposes of this study.

Utility, administrative, and support manning were held constant at the values for the FF 1052, except where they were dependent on crew size. The time required for personnel related functions, such as commissary services, was reduced in proportion to crew size reductions. At sea maintenance of equipment and in port activities were not considered at this point in the analysis. Any deficiencies in these areas were assumed

to be transferred to a shore support activity. This will be discussed in the sections on shore support and ship performance.

Reference 15 describes the Navy Standard Work Week, which was used to assign work to the crew members. The Navy Standard Work Week is intended to be used for planning purposes when preparing ship's manning documents. It divides the week into time required for functions, such as eating and sleeping, and time available for assignment to work. Time lost to training, military duties, and inefficiency was subtracted from the total time available to obtain productive hours of work per week.

NAVY STANDARD WORK WEEK

	At Sea	
Watchstander	74 hr. total	67.25 hr. productive
Nonwatchstander	66	50.00
	In Port	
Watchstander	45 hr. total	34.67 hr. productive
Nonwatchstander	41	28.75

The in port productive hours shown above were reduced by additional 10% to account for leave and training away from the ship.

The helicopter detachment requires a few comments. Some studies (3) have integrated the helicopter detachment into the ship's company, and thus affected a manning reduction. However, a ship capable of carrying a helicopter doesn't always have a helicopter detachment aboard, and thus the integration tends

to break down. For this thesis the helicopter and it's crew were considered to be part of the payload, and thus not subject to integration or reduction in size. In addition, services provided by the ship's crew (primarily fire fighting during flight operations) were assumed to be constant. It is recognized that some reduction in helicopter manning is possible if the expense of cross training is accepted, or if a more reliable helicopter is developed. However, the manning for the helicopter detachment remains at three officers and eleven enlisted for all eight ships investigated in this study.

The development of the crew and equipment options which has just been discussed is the most important part of this thesis. The crew size and the equipment load are inputs to the rest of the analysis for each ship. The final output and conclusions are no better than the information and assumptions on which the crew size and supporting equipment are based.

The results will be more accurate for the ships with larger crews compared to ships with smaller crews. This is because large crews are based on operating ships, or ships under construction, while the small crews are based on systems or concepts which nave not been tested in service. The validity of ships 4 through 8 depends largely on the accuracy of reference 3. If the systems and concepts discussed in reference 3 perform satisfactorily, ships 4 through 8 will be feasible. If the systems in reference 3 are not developed, ships 4 through 8 may

well be infeasible.

The ships in this study are unconventional when compared to other Naval ships. It was assumed that Naval Regulation and tradition would accomodate their unusual characteristics. In practice regulations and traditions change slowly, and these ships would meet opposition if they were introduced into the fleet.

2.2 The Ship Design Model

The Center for Naval Analyses (CNA) synthesis model CODESHIP (16) was used to determine the ship impact of the various crews and equipment used in the study.

A synthesis model takes as input information a ship designer is likely to have at the start of conceptual design, such as, payload, propulsion plant type, and hull coefficients. The output of the model is estimations for the ship's characteristics such as, length, displacement, and cost. This estimation is based on regression analyses of past designs. A flow diagram from reference 16 for the CODESHIP model is shown in Figure 3.

Reference 16 describes the ship synthesis model CODESHIP in it's original form. An updated version supplied by CNA has the following added features:

Gas turbine power plant option

Updated data base

Updated payload shopping list (17)

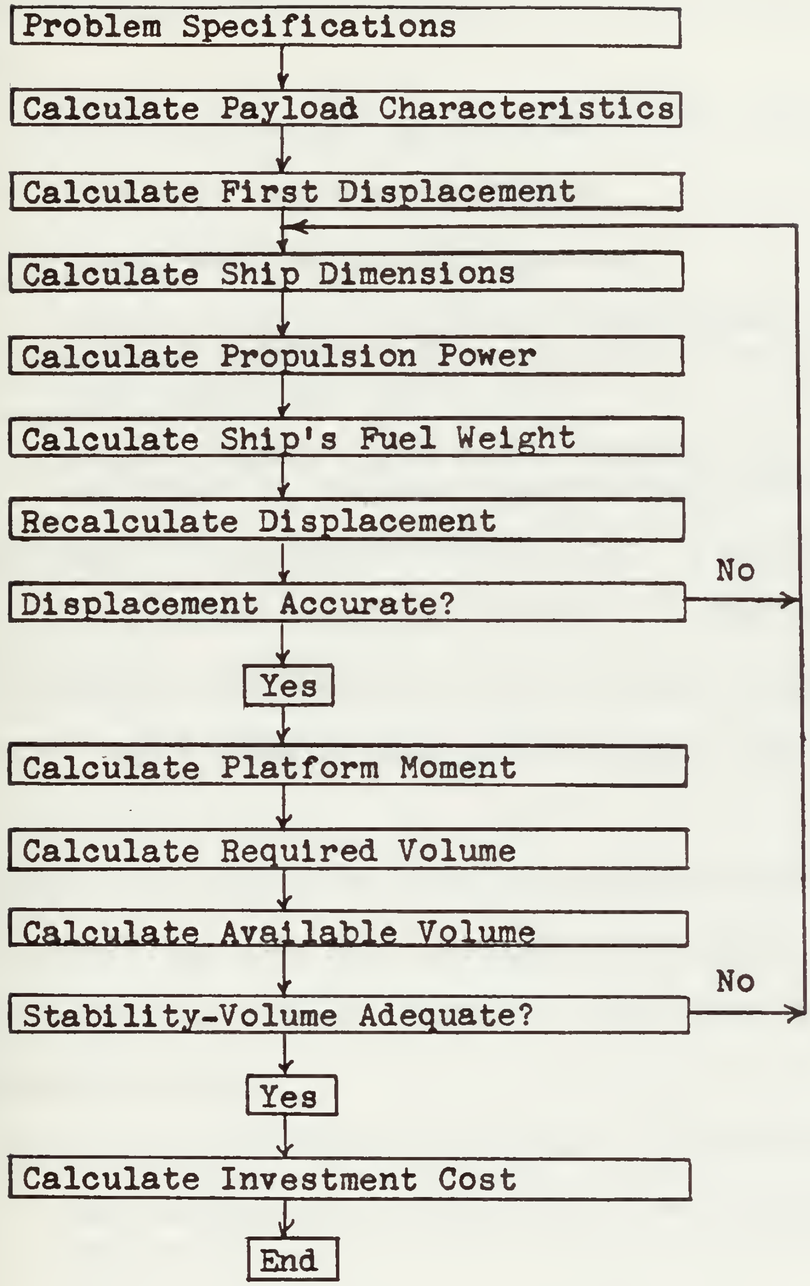

Figure 3. CODESHIP Calculation Approach (16)

For this application a number of additional changes were required.

- 1970's habitability standards were included
- Electrical heat was assumed
- Diesel generators were assumed
- The hull weight estimation was reduced by 10% because CODESHIP tends to overestimate the hull weight for small ships
- The gas turbine plant cost estimation was increased to reflect recent cost information (18)

The impact of improved habitability, electrical heat, and diesel generators was based on the FFG 7. The change in hull weight estimation was based on the CODESHIP documentation itself. (17) These changes were incorporated into the CODESHIP model.

Because the object of this analysis was to evaluate the impact of crew and equipment changes, all other inputs to the synthesis model were held constant. The ships in the study were assumed to have:

- Hulls geometrically similar to the FF 1052
- Gas turbine main propulsion (two LM-2500 engines)
- Four 1000/kw diesel generators
- Electrical heat
- Habitability standards similar to that of the FFG 7

The fact that all the ships in the study have the same hull coefficients, but different displacements and lengths,

affects hull performance. The optimum hull geometry for the FF 1052 may not be the optimum geometry for a smaller ship. In comparison the FF 1040 and FF 1052 classes cover the same size and speed range as the ships in the study. The hulls of the FF 1040 and FF 1052 are a close match, thus the use of geometrically similar hulls for all the ships in the study will not adversely affect the results.

Gas turbines were used in every ship, except ship 1, which was assumed to be a 1200 psi steam plant for crew selection. In addition, the Navy has made the decision to use gas turbines in all the recent escort designs. The gas turbine main propulsion system led to the selection of electrical heat and diesel generators. Based on the FFG 7, the electrical power required for these ships is 1000 kilowatts greater than required for the FF 1052 because of the electrical heat. This was assumed to be constant for all the ships in the study.

Note that the two LM-2500 gas turbine engines provide a total of 40,000 horsepower compared to the 35,000 provided by the 1,200 psi steam plant in the FF 1052. This results in the ships in the study having a higher speed than the FF 1052. In addition, the smaller ships developed in the study will have a slight speed advantage over the larger ships. This must be taken into account when comparing the performance capabilities of the eight ships.

Because it was important to analyze a large variation in

crew size, ship 1 was assumed to have the same propulsion plant as the FF 1052 for the purpose of crew selection, even though it has a gas turbine propulsion plant. Thus ship 1 is manned as if it were a steam ship, but input into the ship synthesis model as a gas turbine ship. This avoids the sudden change in ship characteristics that would result if ship 1 was input into CODESHIP as a steam ship, and the rest of the ships in the study as gas turbine ships.

A sample input to the CODESHIP model for the FF 1052 as it was constructed is shown in Appendix 1 along with the results from the program. Also shown is a comparison of the predicted results with the actual FF 1052 characteristics. The close comparison increases confidence in the model. The Center For Naval Analyses has found the CODESHIP model to be accurate to within 15% for virtually all cases, and within 6% for most cases. With the modifications made in this study to make CODESHIP more suitable for escort type ships, the accuracy is assumed to be within 5%. The relative accuracy between the ships in the study should be even better than the absolute accuracy.

2.3 Ship Acquisition Cost

Estimating the acquisition cost of a new ship is a dangerous undertaking for a ship designer. The cost escalation in the ship building industry has run far ahead of that for the economy as a whole. The rapid cost escalation has reduced the

value of past experience and caused cost estimations for ships to be notorious for their inaccuracy. All cost estimations for this analysis were done in terms of January 1974 dollars because this is the last year for which crew costs were available.

The CODESHIP model discussed in the last section has an acquisition cost subroutine and it was used to do the cost estimation. Unlike most cost estimations, which are based on weight groups only, CODESHIP uses a different approach. CODESHIP divides acquisition cost into three parts.

Construction Cost

> This is the cost incurred in the builders yard. This includes material, labor, and services normally provided by the builder.

Government Furnished Equipment Cost

> This is the cost of components provided by the government to the shipbuilder. It is covered in the Payload Shopping List. (17)

Development and Other Cost

> This is the cost incurred by the government during the design and development stage. Also included here is the cost of test and instrumentation, and the cost of stock spares.

The Center For Naval Analyses provided the information required to calculate construction cost. This was based on historical data from shipyards which actually built escorts in 1974. This information is presented in Table 2.

The cost of Government Furnished Equipment is part of the

TABLE 2

ASSUMED CONSTRUCTION COST

Year of cost	1974
Number of ships produced	50
Inflation rate from base year (1968)	7%
Labor rate	$4.98/hr.
Overhead	92%
Design labor rate	$5.67/hr.
Profit rate	10%

data base of the CODESHIP model. The only equipment addition not covered by CODESHIP was the equipment required to support reduced bridge manning. Discussion with personnel at Naval Ship Engineering Center revealed a strong feeling that an integrated bridge console, with automatic steering and collision avoidance devices, would cost no more than the equipment presently installed. Because of this, the cost changes in bridge equipment were disregarded.

Development and other cost were input to the CODESHIP model as zero to permit a more detailed analysis by hand. The output was then adjusted to account for development, test and instrumentation, stock spares, and construction plans cost. These costs were estimated using reference 19 (First Cost of Ships Report, Oct. 1975) as a guide. The total cost of development and other cost for each ship in the study was averaged over an assumed 50 ship buy, and this average cost added to the CODESHIP output to obtain total acquisition cost. The cost of construction plans and stock spares were relatively uniform for all the escort type ships in reference 19, thus a representative value was easy to obtain. The cost of test and instrumentation and development varied widely among the ships in reference 19. The variation was largely dependent on the complexity of the combat system, and in the case of the FFG 7, the use of a new type of power plant. The ships in this study were assumed to use the same power plant as the FFG 7 class,

thus no large outlays for development or testing were required for propulsion. The combat systems, including the software required to permit reduced manning, range from the simple system used on ship 1, to a much more complex system used on ships 4 through 8. The development and other cost were estimated by comparison with ships of similar complexity in reference 19. In all cases zero equipment development and testing cost were assumed because only existing or near term equipment was used.

The acquisition cost estimation is an important part of this analysis. Personnel at the Center for Naval Analyses consider the acquisition cost subroutine to be "sufficiently accurate for trade-off comparisons", but have not determined the error range. The input for construction cost is considered accurate because it was based on historical data. The development cost estimated is probably the most inaccurate element of this analysis, however, the effect on the final results is small. The fact that a 50 ship buy was assumed means that a large error in the development cost estimation will have little impact on the average cost of the 50 ships.

2.4 The Ship Life Cycle Cost Model

The Life Cycle Cost (LCC) of a ship is the total cost associated with the ship from conceptual design until disposal of the ship at the end of it's useful life. For this analysis, it wasn't necessary to evaluate every item in the LCC, but only

those that change with manning. Major items considered were:

Ship acquisition cost

Thirty year crew cost

Thirty year fuel cost

Additional shore support required because of low manning.

The cost of repair parts, ammunition, overhaul, modernization, and supplies were not considered in the model. These items were assumed to be the same regardless of crew size. Some error is involved. The cost of repair parts and overhaul will vary slightly from ship to ship in the study due to different equipment and maintenance philosophy. Also, the cost of supplies (especially provisions) is dependent on crew size. These two factors tend to offset each other because the ships with small crews will tend to use the more expensive plug-in, plug-out maintenance approach, but require less provisions.

The ship acquisition cost was discussed in the last section. The crew cost and fuel cost are clearly items that change with crew size and ship size, and thus required evaluation. All ships require some level of shore support. The only shore support calculated for the ships in the study was for support in excess of the support the FF 1052 requires. The extra shore support is required because of the small crews on some of the ships in the study. The details of the analysis of LCC follow.

2.4.1 Thirty Year Crew Cost

Using the manning options developed for each crew size and reference 20 (Annual Manpower Billet Cost for Life Cycle Planning), the annual cost of each crew was determined. Reference 20 gives the total cost to the Navy for each paygrade and skill in terms of January 1974 dollars. Total cost includes not only pay, but also training, travel, retirement, and other indirect costs.

In business it is a common practice to discount future cost using the cost of capital. It is also common to inflate future cost by some assumed inflation rate. The importance of discount and inflation to a government agency is questionable. Navy practice has been to disregard both effects when conducting trade-off studies. The same procedure was used in this analysis.

2.4.2. Thirty Year Fuel Cost

The ships in the study were assumed to be underway 50% of the time and in port 50% of the time. The assumed underway speed-time profile is shown below.

Speed	Percent of Underway Time
Under 10 knots	11%
10-12	8
12-14	14
14-16	10
16-18	11
18-20	12
20-22	12
22-24	12
24-26	6
26+	4
	100%

Using the FF 1052 speed-power curve (21), the underway profile, and the fuel consumption curve for the LM-2500 engine (22), it was possible to estimate the fuel consumption for a gas turbine powered FF 1052. The fuel rate varied from 1.8 tons/hr at 10 knots to 8.3 tons/hr at 26 knots. This includes an assumed electrical load of 2000 kilowatts supplied by diesel generators with a specific fuel consumption of .6 lb/hp-hr. The weighted average for all underway time is 3.04 tons/hr. The weighted average of fuel use multiplied by the hours underway/year will give the fuel used/year.

The CODESHIP model does not estimate a speed-power curve as part of it's routine, so the average fuel consumption of the ships in the study could not be calculated directly. When a gas turbine powered version of the FF 1052 was run on CODESHIP, it was noted that the fuel consumption at endurance speed was 3.07 tons/hr. This is very close to the average fuel consumption of 3.04 tons/hr just calculated. This relation was assumed to exist for all the ships in the study. Average fuel consumption was calculated by using endurance fuel load in the following equation.

$$\frac{\text{Endurance fuel (tons)}}{\text{Endurance range/Endurance speed}} = \text{Endurance and average fuel rate in tons/hr.}$$

Where: Endurance fuel is CODESHIP output

Endurance range is 4500 miles

Endurance speed is 20 knots

Thirty years of fuel cost were calculated using the relation below.

Average fuel rate x 4380 hr/yr x 30 years x \$94.20/ton=
= Life cycle cost of fuel

The fuel price of \$94.20/ton is equivalant to \$12.00/bb. As with crew cost, no discount or inflation were taken into account.

2.4.3 Additional Shore Support

As mentioned in the introduction to this chapter only shore support in excess of what the FF 1052 requires was calculated in the LCC model. The base level of shore support required by the FF 1052 was disregarded in the LCC model.

Before the cost of the additional shore support could be calculated, the hours required in each skill had to be determined. There are over 100 skill groups aboard the FF 1052. To have analyzed each one separately for each ship in the study would have required too great of detail. The individual skills were grouped into six similar categories. The categories are shown below.

Combat Systems, made up of highly skilled personnel trained in electronics

Operations, made up of personnel who operate the electronics

Deck, made up of personnel who do unskilled work such as hull maintenance.

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Ship Control, personnel who stand bridge watches

Engineering, personnel who maintain and operate the engineering systems

Support, personnel who provide support services to the rest of the crew

The hours available and the hours required per week for each type of manning discussed in Section 2.1 were determined for each of the categories above. Preventive and corrective maintenance manning were determined from the equipment list for each ship. The time available in each of the above categories was calculated based on the Navy Standard Work Week presented in Section 2.1. When hours required exceeded the hours available per week in any of the skill categories, a shortage existed. This shortage was assumed to be transferred to a shore based support group.

This method worked well for the 50% of the time the ships were assumed to be underway because of the data available in the FF 1052 Manning Document. However, no information was available in the manning document concerning in port routine. The DD 963 Manning Document (14) is the first to cover in port routine. The reason in port manning received little attention before the DD 963 Manning Document is because the worst case manning condition was assumed to be at sea under war time conditions. Recently with the provision for six-section liberty in port, plus more time required for leave and training away from the ship, in port manning has approached the limiting

factor. This shift requires that in port manning receive as much attention as at sea manning.

The DD 963 and the ships in this study are similar in many ways. They have the same type of mission and to a large extent the same type of equipment. They both have helicopters, a large sonar, the same 5-inch gun, and the same type of power plant. Because of this, the ratios of in port to at sea work load for the DD 963 were used to estimate the in port work load for the ships in this study. From this, plus the assumed in port watchstations, the amount of outside support required per week could be determined for in port in the same manner as it was done for at sea. Because a 50% underway time was assumed, the results for at sea and in port could be averaged to provide the average amount of shore support required. The assumed in port watchstations for the ships in the study are shown in Appendix B.

After the hours and type of support that will be required from shore based commands was determined, the cost was calculated. Shore based personnel are assumed to do 29 hours/week of productive work by the DWS group at the Naval Ship Engineering Center. The shore support was assumed to be performed by Navy personnel stationed at commands dedicated to the support of the low manning ships. As an average personnel in paygrade E-3 were assumed to do the unskilled work while E-5's of the appropriate skill category do the skilled work. An

average cost for the personnel in each skill category was calculated. The results are shown below.

Combat Systems	$20,499/year
Operations	15,365
Deck	10,545
Ship Control	16,549
Engineering	18,300
Support	17,496

With the hours of shore support required per week, the work week, and the cost of each skill category available, the cost of thirty years of shore support was determined.

The method used to estimate crew cost is accurate, assuming that the results of the manning model are accurate. The fuel use determination is based on the assumption that average fuel rate and endurance fuel rate are the same. The fuel cost for the thirty year life of the ships is assumed to be $12./bb. The assumption about average fuel rate is reasonable based on CODESHIP estimates, but the $12./bb may not be. A sharp increase in fuel cost would give an added advantage to small ships in a LCC comparison due to their lower fuel use. This could change the relative ranking of the ships in the study.

The cost of shore support is based on the FF 1052 Manning Document, and the assumptions that elements of the work load are related to crew or ship size. The FF 1052 Manning Document has been refined using information gathered on operating

FF 1052 class ships, and is considered accurate. Administrative and support functions were assumed to be handled in a conventional manner on all the ships in the study, thus the major assumption that some of the work load is proportional to the crew size is realistic. The cost of shore support assumes that the shore support activities are fully utilized. If they are not used to full capacity, the cost will rise. Any inaccuracies here apply to all the ships in the study, thus the relative accuracy is unaffected.

2.5 Ship Performance

As discussed in Section 2.1, the intention was to hold performance constant on all the ships in the study. This was done by adding equipment and streamlining procedures to allow the small crews to perform as well as the large crews. In reality this was not possible, and performance decreases as crew size decreases.

The performance was evaluated on the ability of the ships to perform the functions in Table 1. Each ship was rated in each category using the scale below.

9	Very greatly improved
8	Greatly improved
7	Improved
6	Slightly improved
5	Baseline (same level as the FF 1052)
4	Slightly reduced

3	Reduced
2	Greatly reduced
1	Very greatly reduced
0	No capability

Some of the functions can be performed well with a small crew due to automation. Other functions, such as fire fighting after battle damage, are manpower intensive, and thus performance falls in almost direct proportion to crew size.

The evaluation was subjective, taking into account the following factors.

The crew size and composition

The watch stations manned

The type and performance of the equipment installed

The doctrine under which the ship operates

From this an overall description of the capabilities of each ship was developed.

No firm approach to performance evaluation was developed, thus the results are based primarily on the author's subjective evaluation. As a result, this part of the analysis contains the greatest uncertainty. Because of the uncertainty, no quantitative ranking of the ships in the study was attempted. The qualitative ranking in performance is based primarily on the time available to perform critical maintenance functions. In addition to producing a qualitative ranking, it is felt that this method can identify ships which would be unacceptable

because of equipment availability problems. The identification of ships with unacceptable performance is important because they will have a low Life Cycle Cost, and thus would otherwise be an attractive option from a standpoint of cost.

2.6 Impact of Reduced Shipboard Manning on the Personnel System

The present training system of the Navy relies heavily on shipboard training. After basic training a large percentage of personnel go directly aboard ships. Other personnel receive training in a particular skill before reporting aboard ship, but in both cases, shipboard training and experience are required before the individual can be effective. During the period of shipboard training, the trainees perform the large amount of unskilled labor required aboard conventionally manned ships.

A ship with reduced manning has less requirement for unskilled labor. In addition, the skilled technicians and operators aboard ship have less time to devote to training others. Thus changes will be required in the training system.

The crews produced using the methods in Section 2.1 are broken down according to paygrade to give some indication of how severe the problem will be. Among the points considered were:

The type and number of personnel required

The amount of training required

Shipboard training

Detailing procedures

Regulation barriers

This part of the analysis is outside the main thrust of the thesis, and the accuracy is unimportant as far as the results of the rest of the analysis are concerned. The section on impact on the personnel system was included because some of the information developed in this thesis led to conclusions about the personnel system.

2.7 Summary and Evaluation of the Analytical Approach

The analytical approach just presented was intended to be a consistant method of determining the following for each ship in the study.

Crew size, equipment and doctrinal changes required

Ship size

Ship acquisition cost

Life Cycle Cost

Performance of mission

Impact on personnel system

In general, all of the information produced above tends to be more accurate for the ships with large crews than for the ships with small crews. This is because the large crews are based on operating ships or ships under construction, while the small crews are based on systems or ideas that have not been tested in service. The most important point concerning

the accuracy of this analytical approach is that this is a comparative study.

The absolute accuracy of the results of this study is not critical. What is important is the relative accuracy between the 8 ships in the study. Thus, while it may not be possible to determine a completely accurate displacement or LCC for the ships in this study, it is possible to be certain of their relative standing. The same holds true for ship performance and cost effectiveness.

CHAPTER 3

RESULTS

The results of the analytical methods discussed in Chapter 2 are presented in this chapter.

3.1 Results of the Manning and Equipment Model

A summary of ship 1, the baseline ship, is shown below using information taken from references 11 and 23.

Crew	18 Officers, 18 CPO's and 240 other enlisted
Antisubmarine Weapons	1 Antisubmarine missile launcher (ASROC)
	2 Antisubmarine topedo tubes
Guns	1 MK 42 5-inch dual purpose
Missiles	1 Basic Point Defense Missile launcher
	2 Antiship missiles carried in ASROC launcher
Electronics	SQS-26CX sonar
	SPS-40 air search radar
	SPS-10 surface search radar
	MK 68 gun fire control radar
Aircraft	1 Light Airborne Multi-purpose System (LAMPS) helicopter
Engineering	1 35,000 horsepower-geared steam turbine
	2 1200 psi boilers

The following major watch stations are required to operate the ship in the wartime steaming condition (Condition III).

Bridge Watch	2 officers	11 enlisted/watch
Command and Control	1	12
Weapons Control		10
Engineering Control		15

A summary of ships 2 through 8 is shown in Table 3, and a detailed listing of each ship's crew is presented in Appendix C. The changes in equipment or procedures represent changes from the previous ship, thus the table must be read from beginning to end to be understood. The manning change is based on the manning documents developed for each ship in the study. The information on space and weight changes is predominantly from reference 16, with the balance from reference 3, or conversations with Naval Ship Engineering Center personnel.

The weight and space changes in Table 3 are intended to reflect the direct changes due to equipment substitutions and additions. The change in ship displacement is larger. No direct weight or space changes were assigned to personnel changes when the Postal Clerk, Maintenance Administrator, Personnel Clerk, and Ship Servicemen were eliminated from the crew. These personnel were no longer required full-time because of reductions in crew size. The facilities they used, such as a laundry or office space, are still required to some lesser extent. The CODESHIP synthesis model reduces the size of these crew related

TABLE 3

DESCRIPTION OF THE SHIPS DEVELOPED

SHIP 2

No. Off.	No. CPO	No. Enl.	Total Crew	Changes in Equipment or Procedures	Man. Change	Wt. Change (tons)	Space Change (ft^2)
13	16	170	199	Light Weight 5" gun replaces Rapid Fire 5" gun	-9	-54	0
				Naval Tactical Data System (NTDS) replaces conventional Command and Control	-6	15	0
				Gas turbine main propulsion plant replaces manual 1200 psi steam plant	-31	*	*
				FFG 7 ship control system replaces the conventional ship control system	-11	0	0
				Officers served from the crews commissary	-2	0	0
				Junior Officer of the Deck, Navigator, and Deck Division Officers eliminated	-5	0	0
				Postal Clerk and Maintenance Administrator eliminated	-2	0	0
				Second order effects	-11	0	0

* The steam plant was assumed for manning purposes only, thus there is no change in space or weight.

TABLE 3 (continued)

DESCRIPTION OF THE SHIPS DEVELOPED

SHIP 3

No. Off.	No. CPO	No. Enl.	Total Crew	Changes in Equipment or Procedures	Man. Change	Wt. Change (tons)	Space Change (ft^2)
13	15	143	171	The dual purpose Mk 92 fire control (F.C.) radar replaces the Mk 68 gun F.C. and the BPDMS missile F.C.	-6	-1	-40
				Improved communication equipment (similar to DD 963 in ref. 14) allows a 2 man watch in place of 3 man watch	-4	-2	0
				Sonar integrated into NTDS, no equipment changes	-3	0	0
				One ship's boat carried	0	-8	-150
				Two man ship control console installed, with 4 man bridge watch	-5	.1	0
				No nuclear weapon capability	-5	0	0
				Second order effects	-5	0	0

TABLE 3 (continued)

DESCRIPTION OF THE SHIPS DEVELOPED

SHIP 4

No. Off.	No. CPO	No. Enl.	Total Crew	Changes in Equipment or Procedures	Man. Change	Wt. Change (tons)	Space Change (ft^2)
12	15	112	139	Automatic digital F.C. system replaces manual system	-5	-4	0
				Vertical launch missiles replace missiles launched from Mk 25 trainable launcher	-1	-9	0
				Automatic detection and tracking equipment added to the sonar and radar	-7	1.5	100
				Part time auxiliary watch in engineering eliminated	-2	0	0
				Maintenance deferred to in port	-8	0	0
				Second order effects	-7	0	0

TABLE 5 (Continued)

DESCRIPTION OF THE SHIPS DEVELOPED

SHIP 5

No. Off.	No. CPO	No. Enl.	Total Crew	Changes in Equipment or Procedures	Man. Change	Wt. Change (tons)	Space Change (ft^2)
12	15	93	120	Improved communication equipment allows one man watch	-2	1	0
				Two man bridge watch	-3	0	0
				Maintenance deferred to in port	-10	0	0
				Personnel record and pay functions transferred ashore	-2	0	0
				Second order effects	-2	0	0

SHIP 6

No. Off.	No. CPO	No. Enl.	Total Crew	Changes in Equipment or Procedures	Man. Change	Wt. Change (tons)	Space Change (ft^2)
12	15	72	99	Dedicated radio talker in combat information center eliminated	-3	0	0
				Maintenance deferred to in port	-15	0	0
				Second order effects	-3	0	0

TABLE 3 (continued)

DESCRIPTION OF THE SHIPS DEVELOPED

SHIP 7

No. Off.	No. CPO	No. Enl.	Total Crew	Changes in Equipment or Procedures	Man. Change	Wt. Change (tons)	Space Change (ft^2)
11	13	64	88	No ship's laundry or store	-3	0	0
				No below decks security watch	-3	0	0
				Maintenance deferred to in port	-3	0	0
				No Supply Officer	-1	0	0
				Second order effects	-1	0	0

SHIP 8

				One man engineering watch	-3	0	0
				Reduced supply support	-1	0	0
				Maintenance deferred to in port	-12	0	0
				Second order effects	-2	0	0

facilities in proportion to reductions in crew size, thus the displacement of the ship is affected appropriately. The space and weight changes for second order effects are shown as zero for the same reason.

Figure 4 shows each ship's crew according to function, while Figure 5 shows the crews according to paygrade. The most striking feature to emerge from Table 3 and Figures 4 and 5 is the sharp drop in manning between ships 1 and 4. Figure 4 shows that the manning reduction is almost entirely due to a reduction in watchstanding. Ship 1 was manned in a fashion similar to the FF 1052 which has a high concentration of watch-standers. A characteristic of many of the watches is that much of the time is spent unproductively. This is especially true on the bridge during all but the most active of watches, and in the engineering spaces where most of the time on watch is spent monitoring equipment and recording gage readings. A second characteristic is the repetitive nature of many of the functions performed, which makes them subject to automation. For example, functions such as steering, recording course changes and instrument readings, and monitoring machinery can be performed by relatively inexpensive automatic devices. The high level of man-hours expended on these functions not only makes them expensive in terms of man-hours expended, but tends to lower the feeling of self-worth of the people involved.

For example, a comparison of ships 1 and 4 reveals the

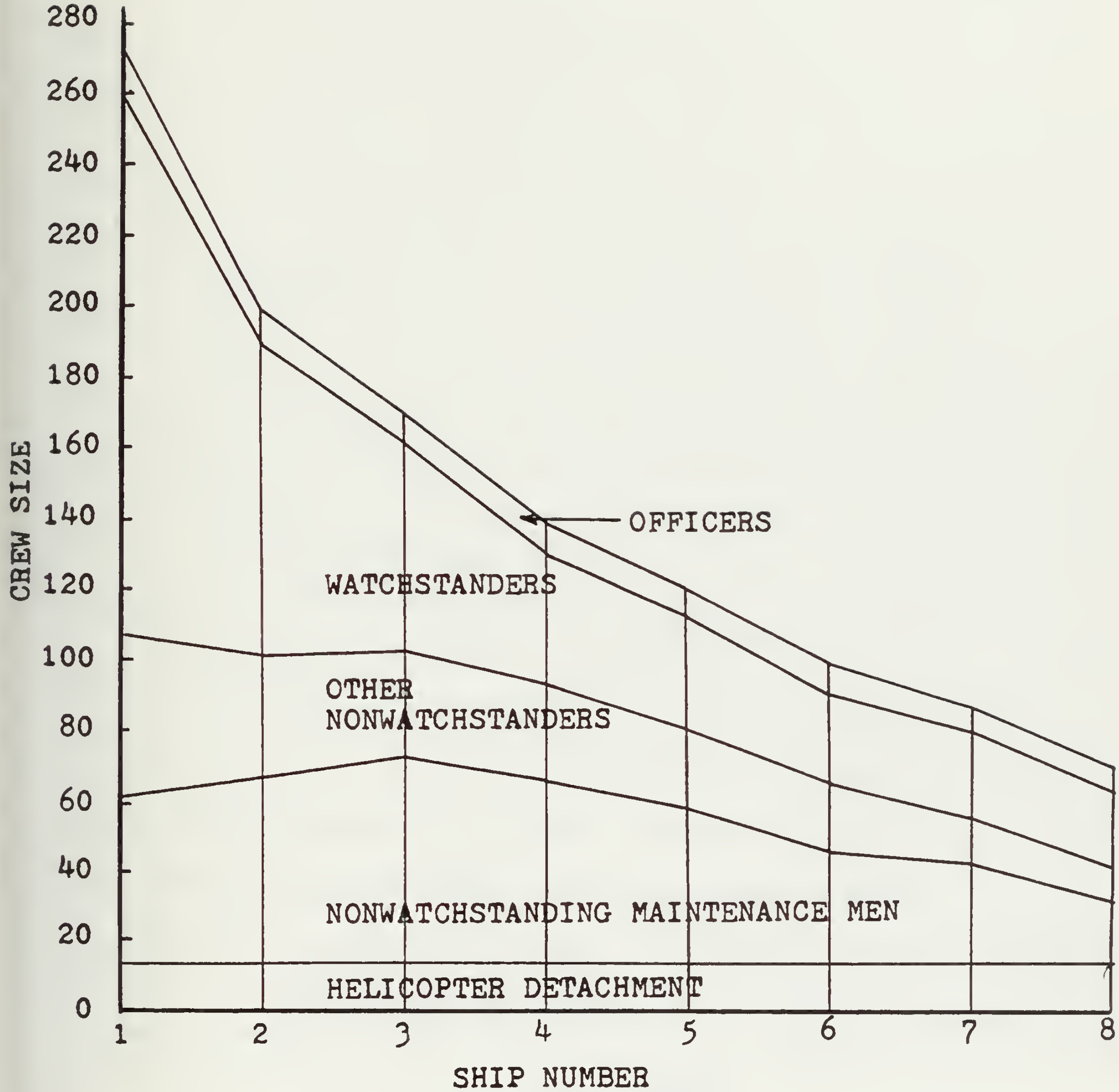

Figure 4. Functional Breakdown of Ship's Crews

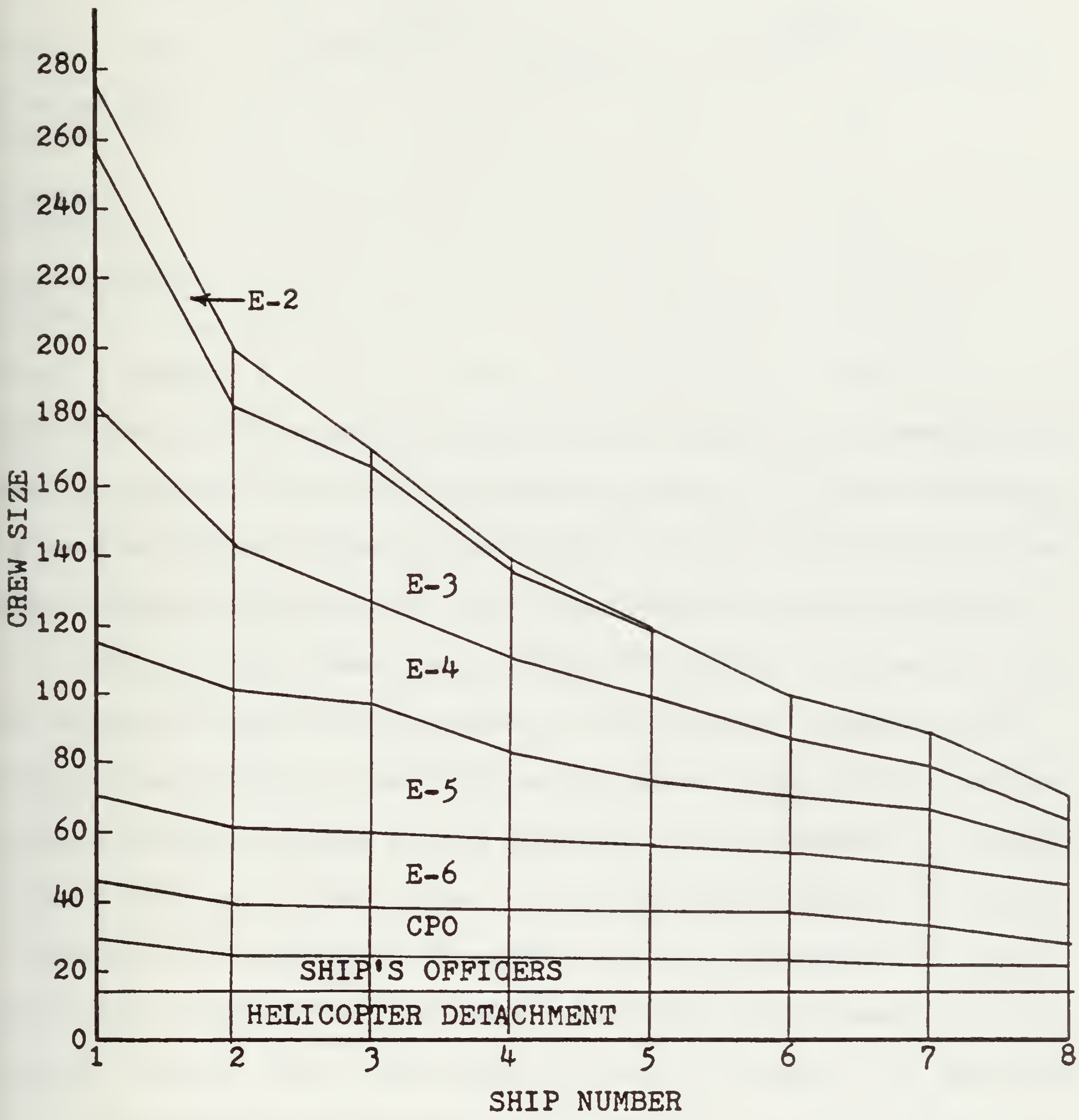

Figure 5. Crew Size and Composition

following personnel required for the major watch station during Condition III.

	Ship 1		Ship 4	
Bridge Watch	2 officers	11 enlisted	1 officer	2 enlisted
Command and Control	1	12	1	3
Weapons Control	0	10	0	3
Engineering Control	0	15	0	2
Total on Watch	3	48	2	10

Ship 4 has a reduction of 75% from the number of personnel it took to perform the same functions on ship 1. This reduction in watchstanding allows the crew size to be reduced by 135 men when support personnel for the watchstanders are eliminated.

Table 3 shows that the equipment changes to make the 135 man reduction are not excessive. The biggest change is the change from steam to gas turbine for main propulsion. Another large equipment change is the addition of 2 computer, 7 display console tactical data system. The computer hardware in ships 2 through 8 is basically the same. What is required is increasingly complicated software. Software has almost no ship impact, but can take years and millions of dollars to develope.

The equipment required on the bridge to support the small deck watch is modest. Three changes were made.

Ship 2

Bridge equipment was integrated into a single console

Automatic steering device added

Ship 3

Collision avoidance device installed

In addition to the equipment changes, the signal and navigation skills were assumed to be integrated into a ship control division. This allows more efficient utilization of personnel.

Ships 5 through 8 are in sharp contrast to ships 1 through 4. In ships 1 through 4 the reduction in crew size is made possible by the addition of equipment or changes in procedure which replaces or aids the watchstanders. The last four ships make reductions in crew size more at the expense of maintenance and administrative functions than by replacing people with equipment. Note that the number of watchstanders remains almost constant on the last four ships.

The last ship, ship 8, has the smallest possible crew with the level of technology allowed in the model. Any smaller crew would result in the crew being unable to accomplish essential operational functions. The feasibility and acceptability of the ships is discussed further in the section on performance.

A direct comparison between the ships developed in this study and the FFG 7 is difficult due to differences in equipment and mission. In terms of crew size only the FFG 7, with 184 men, falls between ships 2 and 3. If the large sonar, ASROC, and 5-inch gun that the ships in the study carry were substituted for the second helicopter and missile system on the FFG 7, the FFG 7 would show only a slight increase in crew size. Thus

it is clear that the FFG 7 is manned similar to ships 2 and 3, and represents a large reduction in manning compared to the FF 1052.

The limitations of the manning and equipment model which were discussed in Section 2.1 should be kept in mind when reading the results shown in Table 3. Of particular importance is the fact that much of the equipment and procedures used on ships 4 through 8 is based on reference 3.

3.2 Results of the Ship Design Model

The CODESHIP model was first run with payload and equipment constant and only the crew size varying. This was done to determine the impact of manning changes on the ships without interference from equipment changes. A summary of the results is shown in Table 4.

A second run of CODESHIP was made with the equipment list varying as noted in Table 3 to support the manning level on each ship. A summary of the results is shown in Table 5.

The acquisition cost is discussed in later sections.

The results of the model for ship length and fuel were as expected. The displacement is reduced by about 25% between ship 1 and 8 in both runs, but length is reduced by only 9%, while endurance fuel load is reduced by only 4.5%. The small reduction in length occurred because all the ships in the study were volume limited. As the required volume was reduced due to

TABLE 4

SHIP CHARACTERISTICS WITH EQUIPMENT CONSTANT

Ship	Crew Size	Displacement (tons)	Length (ft.)	Endurance fuel (tons)	Acquisition cost*
1	276	4276	427	691	72.88
2	199	3926	414	681	70.66
3	171	3801	410	676	69.86
4	139	3654	404	672	68.92
5	120	3568	400	669	68.37
6	99	3474	397	665	67.76
7	88	3410	394	663	67.36
8	70	3342	391	661	66.92

TABLE 5

SHIP CHARACTERISTICS WITH EQUIPMENT VARYING

Ship	Crew Size	Displacement (tons)	Length (ft.)	Endurance fuel (tons)	Acquisition cost*
1	276	4276	427	691	72.88
2	199	3866	412	678	72.53
3	171	3716	409	676	74.37
4	139	3549	402	670	75.63
5	120	3466	398	667	75.55
6	99	3368	395	663	74.93
7	88	3304	392	661	74.52
8	70	3236	389	660	74.08

* Millions of 1974 dollars

smaller crews, the length drops less because volume is a cubic function of length for ships of similar shape. The fuel required for endurance range is a function of the required power at the endurance speed of 20 knots. Power is not a strong function of displacement, and thus endurance fuel is not reduced as fast as displacement. An example is a comparison of the FF 1034 and FF 1044. The displacement of the FF 1034 is 50% of the displacement of the FF 1044, however, the power required at 20 knots for the FF 1034 is 85% of that required for the FF 1044.

The relatively small decrease in required fuel and length have an impact on the LCC of the ships in the study. The cost of fuel and upkeep of the hull did not decrease as fast as ship displacement. This will be discussed further in the section on LCC.

The displacement versus crew size when payload and equipment is constant is shown in Figure 6. Note that ship 1 is over 200 tons heavier than the modified FF 1052, which has exactly the same payload and crew. The only changes are the use of a gas turbine propulsion plant and the improved habitability standards. A steam version of ship 1 was run on CODESHIP to investigate these two changes. The steam version was even larger than ship 1, thus the impact of improved habitability standards is responsible for the 200 ton growth in displacement.

From Figure 6 marginal weight factors for manning can be determined. The marginal weight factor for manning is defined as the change in the full load displacement of a ship when one

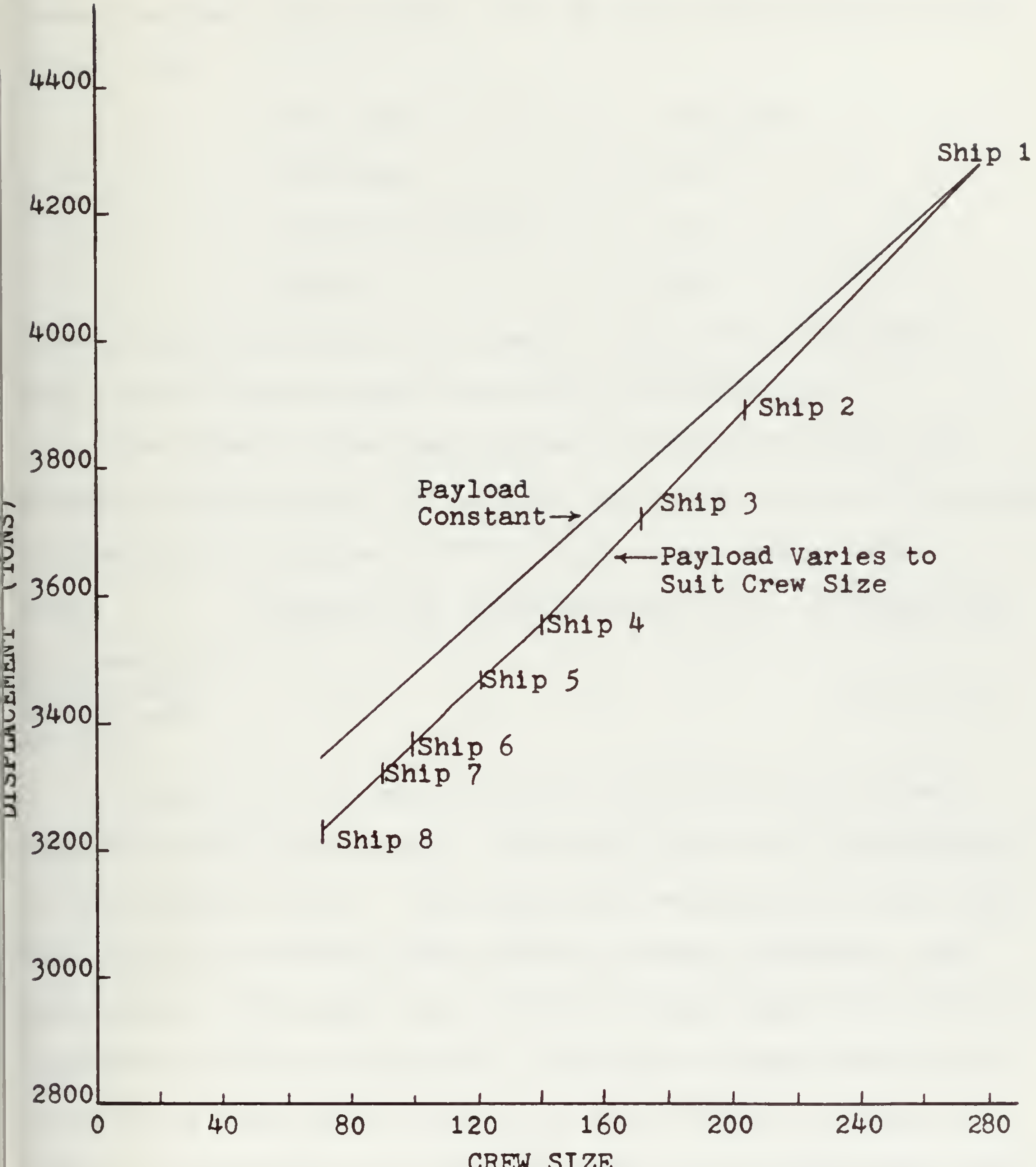

Figure 6. Crew Size Versus Displacement

man is added or removed. It depends on the habitability standards designed into the ship, and on the type of ship as shown below. (24)

Ship Type	Tons/man
Auxiliary	2.7
Aircraft Carrier	3.3
Escort	4.5

These figures show that the impact of the crew is greater on small ships such as those are under discussion here.

From Figure 6 when the payload was held constant, the marginal weight factor for manning was found to be 4.52 tons/man. The results of a number of other studies are shown below.

Study	Cotton (24)	Howell/Graham (25)	DG Study (26)
Tons/man for GT ship and 1970's habitability	4.5	5.3	3.9 to 6.3

A number of factors can cause a variation in marginal weight factors for manning. The model used to do the analyses is the largest factor. This study and reference 24 used CODESHIP, while the others used NAVSEC's surface combatant ship model DD07. The models have different data bases and different approaches to the calculations. The other large factor is the assumptions made about the type of ship to be run. Howell and Graham in reference 24 showed variations in the marginal weight per man depending on:

Constant Speed or Constant Power

C_X and C_p

Whether the ship is Weight or Volume Limited

The size of the ship

As mentioned in Chapter 2, the power plant and the electrical plant were held constant. If these two systems had been allowed to vary with the crew size, the marginal weight factor for manning determined in this study would have been greater.

The displacement versus crew size when payload varies to suit crew size is also shown in Figure 6. This plot reflects the change in displacement when the crew size was reduced and equipment was changed according to Table 3. This series of ship designs is the one that was used in the LCC evaluation.

There are three equipment changes with large displacement impact.

Ship 2

Light weight 5-inch gun replaces MK 42 5-inch gun	-54 tons
NTDS (two computer 7 display) added	+15

Ship 3

Only one boat carried versus two	- 8 tons

The weights above are direct impact. The changes in displacement are larger due to secondary effects.

The reduction in direct payload weight of 39 tons on ship 2 and eight tons on ship 3 can be seen in Figure 6. The slope between ships 1 and 3 is greater than the overall trend. The other equipment changes were too small to be reflected in a

noticeable change in the slope of the displacement curve.

The average marginal weight of one man over the range from ship 1 to ship 8 is 4.71 tons/man when payload changes are constant. It is interesting to compare this number, which represents the combined effect of crew and equipment changes, with the figure of 4.52 tons/man when only the crew is changed. It would have been reasonable to expect a smaller marginal weight/man because equipment had to be added to support the lower manning level. The reverse effect is due almost entirely to the large decrease in weight which came about with the replacement of the heavy MK 42 gun with the light weight MK 45. It should be pointed out that the substitution was made because of the large manning reduction associated with the MK 45 gun and not the weight savings.

For the changes among the systems with lower weight impact, the newer, more capable, low manning systems were as a rule smaller, lighter, and require less support than the systems they replaced. This is due to the fact that the new systems tend to use solid state digital equipment while the older systems tend to use equipment of the tube technology era.

The approach used in this study gives a technological advantage to the ships with low manning because they have more modern equipment. In reality, all ships built in the same time frame would share the same technology. The important point is that the equipment required to permit much smaller crews need

not have a large impact on the displacement of the ship.

One final point needs to be mentioned. The CODESHIP model does not make adequate distinction between the space and weight requirements of officers, Chief Petty Officers (CPO's) and other enlisted. CODESHIP makes a distinction only in the area of personal effects, when in reality officers and CPO's have greater amounts of furnishings and space. In conventionally manned ships this is no problem because the ratios of officers and CPO's to the rest of the crew is more or less constant. Such is not the case in this study. As the crew size is reduced, the ratio of officers and CPO's to the rest of the crew increases. This leads to a small overestimation in the CODESHIP estimation of the marginal weight per man. This effect was noted, but no specific correction was made.

3.3 Results of the Acquisition Cost Model

Using the results shown in Table 3, it is now possible to estimate the cost required for construction plans, Test and Instrumentation (T&I), stock spares and development. Using reference 19 as discussed in Section 2.3, Table 6 was produced. The total cost increment shown for each ship was added to the cost output of the CODESHIP model to obtain total ship acquisition cost.

Construction plans and stock spares cost would not be expected to vary much with ship size or complexity for small escorts. This belief was reinforced by reference 19, which showed

TABLE 6

ASSUMED END COST INCREMENTS*

Ship Number	1	2	3	4	5	6	7	8
Construction plans cost	.8	.8	.8	.8	.8	.8	.8	.8
Test and instrumentation cost	.1	.3	.5	.7	.7	.7	.7	.7
Stock spares cost	.1	.1	.1	.1	.1	.1	.1	.1
Development cost	.1	.5	.8	1.0	1.0	1.0	1.0	1.0
Total	1.1	1.7	2.2	2.6	2.6	2.6	2.6	2.6

* Costs are in millions of 1974 dollars averaged over an assumed 50 ship buy.

only small variation in cost in these categories for small escort ships. The values shown in Table 6 are average values assuming a 50 ship buy.

Development and T&I were estimated to vary with ship complexity as shown in Table 6. These results are based on a subjective comparison of the ships in the study with the ships in reference 19. There is a great deal of uncertainty in these results because of the method used, and because some of the ships in the study are more complex than any represented in reference 19. The error associated with this method has a relatively small impact on the final results because the error is spread over each of the 50 ships in the assumed buy.

The acquisition costs produced when all equipment and payload items were held constant (as in FF 1052) and only manning varied, is shown in Figure 7. Also shown in Figure 7 is the acquisition cost produced when payload and equipment varied to suit the crew size. When the payload was held constant and only the crew size varied, the plot of acquisition cost versus manning was a straight line. The acquisition cost varies from $72,880,000 for ship 1 with a crew size of 276, to $66,920,000 for ship 8 with a crew of 70. The marginal cost per man was found to be $28,932 in terms of 1974 dollars. Other recent results are shown below.

Source	Year Dollars	Marginal Cost
Howell and Graham (25)	1976	$49,770/man
Sejd (27)	1973	23,300

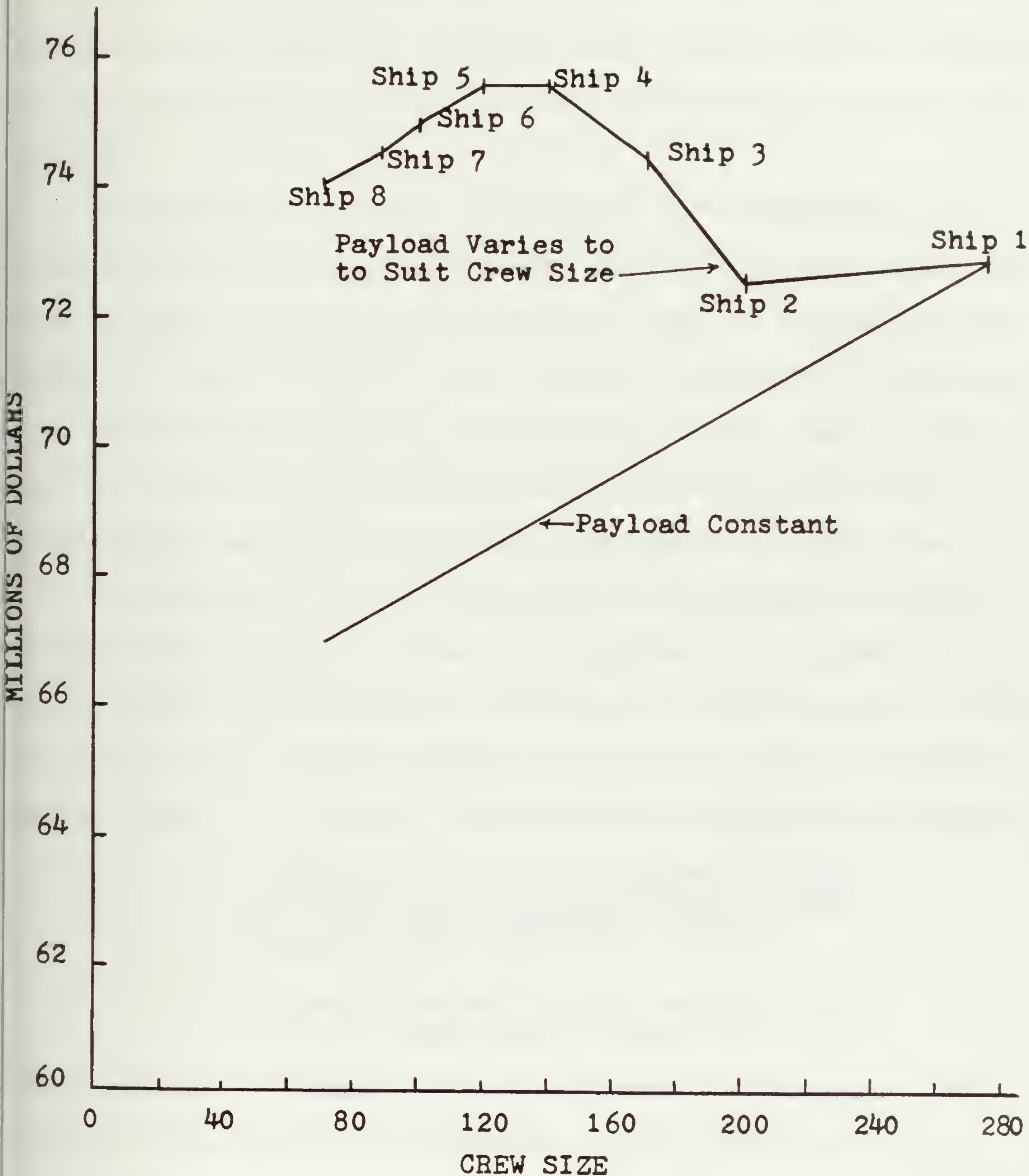

Figure 7. Crew Size Versus Ship Acquisition Cost

The results of this study fall between the two shown above. The difference among the marginal cost results above is largely due to increases in the cost of ship acquisition between 1973 and 1976.

As mentioned in the last section, the displacement is reduced by 25% between the largest and the smallest ship. The cost is only reduced by 8.2% however. This is because the reduction in size is in the hull, which is relatively less expensive than the other parts of the ship. A large part of the cost of a ship is in the electronics and weapons and their development, and this is the same regardless of ship size.

The CODESHIP run when equipment and payload were varied to suit the crew size is the more important of the two. Here the reduction in acquisition cost due to a smaller crew is offset by the cost of the equipment required to make up for the smaller crew. The largest items added in terms of cost were:

> 2 computer 7 display computer system (for both NTDS in ships 2 and 3, and for the fully integrated systems starting with ship 4)
>
> Automatic Detection and Tracking (ADT) systems (Starting with ship 4)

Other equipment changes had little impact on the cost. For example, the cost of an integrated bridge console is little different from the conventional equipment it replaces, and the dual purpose fire control system is comparable in cost to the two systems it replaces. Thus the slope of the cost curve

between ships 4 and 8 is very close to that of the curve assuming payload constant.

When equipment and payload vary note that the acquisition cost of ship 2 is less than for ship 1, even though an expensive computer system was added. This is because most of the crew reduction occurred as a result of the switch from steam to gas turbine main propulsion. The cost of these two systems is basicly the same and the reduction in acquisition cost due to a smaller crew more than offsets the cost of the computer system. Ships 3 through 8 require some expensive equipment additions, thus the acquisition cost increases. The manning reductions aboard ships 5 through 8 were made predominantly by deferring maintenance until in port. The cost trend between ships 5 and 8 would be different if a different approach to maintenance had been used. The cost shown in Figure 7 assumes that maintenance the crew is unable to accomplish is simply transferred ashore. If redundance, self-testing, plug-in plug-out, or other devices had been used to reduce the time required for maintenance, the ship acquisition cost for ships 5 through 8 would be substantially higher.

Note also that when equipment is varied, the cost trend runs counter to the weight trend. In terms of cost, the new equipment tends to cost as much as the old (in the same year dollars) even though the new equipment is smaller. Thus the cost per ton of the smaller ships rises. It appears unlikely

that ship acquisition cost can be reduced by building the smaller ships permitted by smaller crews.

3.4 Results of the Life Cycle Cost (LCC) Model

As discussed in Chapter 2, the elements of Life Cycle Cost (LCC) covered in this analysis were:

Ship Acquisition Cost

Crew Cost

Fuel Cost

Cost of Added Shore Support

The results of the crew and fuel cost calculations are shown in Table 7.

Table 8 shows the average hours of shore support required per week in each of the skill categories for each ship in the study. The detailed results for each category are shown in Appendix D. The negative numbers in Table 8 are the average hours of shore support required per week in each category. The positive numbers are the hours per week available in excess of requirements. The assumption was made that excess hours in one skill category could not be transferred to a category with a shortage of available hours. This assumption is valid because of the high degree of training required for most jobs, and because Navy traditions and regulations precludes the skilled workers from being assigned to unskilled labor. The last column shows the thirty year cost of the required shore support. This can then be combined with ship, crew, and fuel cost to

TABLE 7

THIRTY YEAR CREW AND FUEL COST

Ship	Crew Size	Crew Cost*	Endurance Fuel (tons)	Fuel Cost*
1	276	132.96	691	38.014
2	199	98.65	678	37.299
3	171	86.72	676	37.189
4	139	72.35	670	36.859
5	120	61.86	667	36.694
6	99	53.88	663	36.473
7	88	47.65	661	36.363
8	70	36.89	660	36.308

* Thirty year cost in millions of 1974 dollars

TABLE 8

AVERAGE MANPOWER SHORTAGE OR SURPLUS IN HOURS/WEEK

Ship	Combat Systems	Operations	Deck	Ship Control	Engineering	Support	Support Cost*
1	-	-	-	-	-	-	-
2	370	284	- 10	157	- 41	60	.895
3	414	116	- 11	99	- 28	109	.650
4	366	62	-193	56	-108	79	4.150
5	191	51	-234	11	-158	- 37	7.005
6	21	7	-325	-22	-375	- 27	12.158
7	- 15	-62	-361	-20	-370	-113	15.210
8	-269	-98	-396	-20	-486	-213	25.502

* Thirty year cost in millions of 1974 dollars

give a modified LCC. This is shown in Figure 8.

A number of interesting points emerge from Figure 8. The first is the large percentage of LCC taken up by crew cost in ship 1. The cost of the crew is 54% of the items included in this LCC estimate, compared with 29% for ship acquisition cost. If full LCC was available, the percentage devoted to ship acquisition cost would be even less. In spite of this, when a new ship is proposed the attention of the Congress, the Navy, and the public, is focused on the acquisition cost of the ship.

Some progress toward reducing LCC has been made in the latest escort type ship to be built. The FFG 7 falls between ships 2 and 3 in this study in its approach to manning and automation. In a ship of this type the crew cost falls to approximately 45% of LCC. The percent of LCC devoted to crew cost continues to decline as manning is reduced. However, the cost of shore support becomes an important factor beginning with ship 4. Thus while crew cost declines to only 21% of LCC by ship 8, the total manpower cost (crew and shore support) of ship 8 is 36%. In fact, by ship 8 the cost of manpower has leveled off in terms of both total amount and percentage.

When ship acquisition cost is plotted on the compressed scale of Figure 8, and compared with the other costs shown in the figure, it appears almost constant. This indicates that several million dollars extra spent on ship acquisition to reduce manning (or for any other purpose) is not a large sum

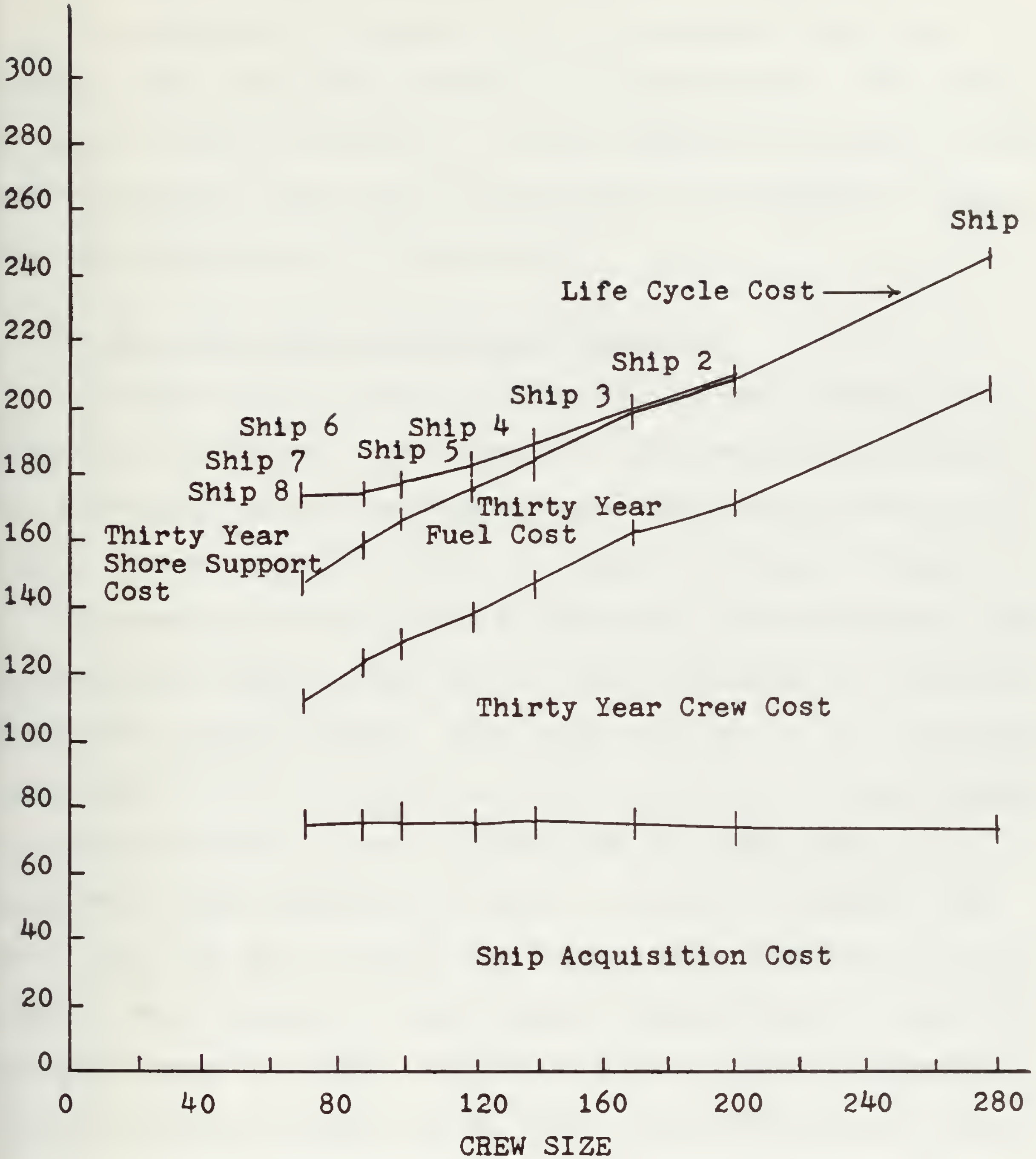

Figure 8. Life Cycle Cost Versus Crew Size

when viewed with all the other components that make up LCC.

As mentioned in Section 3.2, the required fuel load changed very little with changes in displacement. The result of this is seen in Figure 8. As was expected, the cost of fuel over the thirty year life of the ships in the study is about the same regardless of displacement.

3.4.1 The Work Breakdown by Function

At this point in the analysis, sufficient information is available to determine the amount of time required for each of the functions, such as watchstanding, aboard the ships in the study. The results for the at sea case are shown in Fugure 9.

The total time in Figure 9 represents the productive time available per week. Time lost to inefficiencies and military diversions are not shown. Note that over 57% of the productive time aboard ship 1 is spent on watch, but that this percentage is reduced sharply between ships 1 and 4. Only 33% of the productive time available on ship 4 is spent on watch. The FFG 7 with 184 men is shown for comparison. The FFG 7's workload is very similar to the workload aboard ship 3. Thus the manning aboard the FFG 7 represents a great deal of progress from the manning aboard the FF 1052. The definition of Administration and Utility Manning is slightly different in the FFG 7 Manning Document when compared to the FF 1052 Manning Document. This change in definition is responsible for the change in relative value of Administration and Utility Manning aboard the FFG 7.

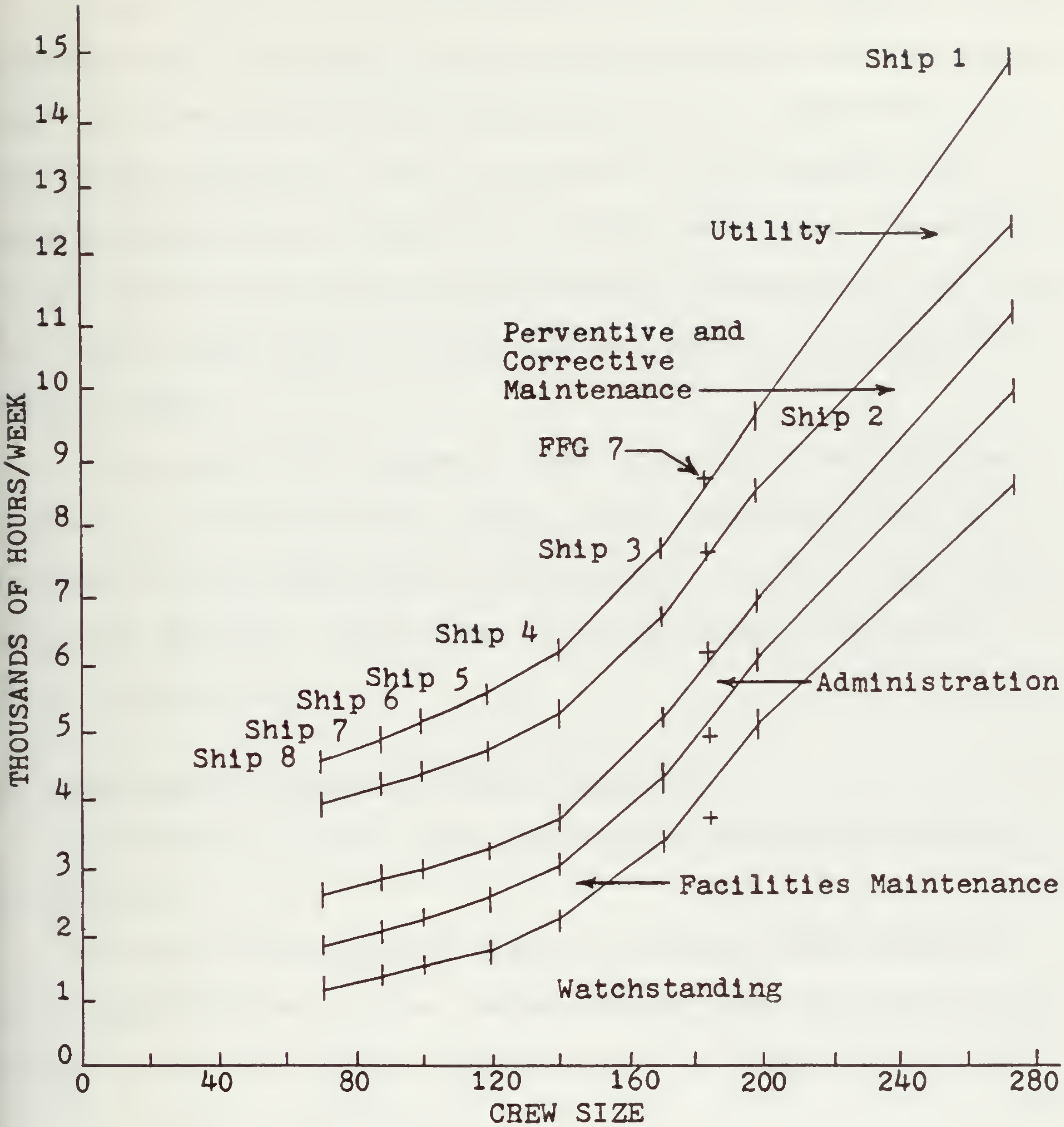

Figure 9. Required Hours Per Week Versus Crew Size

In addition to the sharp reduction in time spent on watch between ships 1 through 8, note that the smaller crews require less time devoted to Facilities Maintenance, Administration, and Utility Manning. This is a result of the second order effects discussed in Chapter 2. At the same time, the amount of Preventive and Corrective Maintenance increases on the ships with small crews due to the equipment required to support the reduced crews.

It is clear from Figure 9 that in order to reduce crew size below the 100-140 man range, sharp reductions will be required in the time spent on Maintenance, Utility, and Administration Manning. Reductions in watchstanding alone will not be sufficient.

3.5 Results of Ship Performance Analyses

The results of the ship performance analyses are shown in Table 9.

The two most important areas to consider when judging a ship's performance are the combat system, and the engineering plant. The combat system aboard ship 1 is characterized by:

Manual operation

Many operators in a hierarchical required to engage a hostile contact

Voice communication between decision makers and operators

Back-up and casuality modes of operation possible

TABLE 9

PERFORMANCE EVALUATION

	Ship							
Antiair Warfare	1	2	3	4	5	6	7	8
Detect aircraft at long and short range	5	5	6	8	8	8	8	8
Engage aircraft with five-inch gun	5	6	7	8	8	8	8	8
Engage aircraft with missiles at short range	5	6	7	8	8	8	8	8
Control aircraft	5	5	5	6	6	6	6	6
Antisubmarine Warfare								
Detect submarines at long and short range	5	5	5	6	6	6	6	6
Engage submarines at long and short range with conventional weapons	5	5	5	5	5	5	5	5
Engage submarines at long range with nuclear weapons	5	5	0	0	0	0	0	0
Use own helicopter in antisubmarine warfare role	5	5	5	5	5	5	5	5
Surface Warfare								
Detect surface contacts	5	4	4	4	4	4	4	4
Engage surface contacts with gun	5	6	7	8	8	8	8	7
Conduct electronic warfare	5	6	6	6	6	6	6	5
Conduct naval gun fire support	5	4	4	4	4	4	4	4
Use own helicopter in surface warfare role	5	5	5	5	5	5	5	5

TABLE 9 (continued)

	Ship							
Mobility	1	2	3	4	5	6	7	8
Steam at full power	5	5	5	5	5	4	4	3
Repair propulsion and auxiliary systems	5	5	5	4	4	3	2	1
Control damage	5	5	5	4	4	3	2	1
Maintain damage security	5	5	5	5	5	4	3	3
Special Warfare								
Surveillance and reconnaissance	5	5	5	5	5	5	5	5
Visit, search, and prize crew	5	5	4	4	3	3	3	2
Command and Control								
Communicate by visual and electronic means	5	5	5	4	4	4	4	4
Process message traffic	5	5	5	5	5	5	5	5
Function as antisubmarine warfare control ship	5	6	6	6	6	6	6	6
Noncombat Operations								
Man overboard	5	5	5	5	5	5	5	5
Medical care	5	5	5	5	5	5	5	5
Administration and supply support	5	5	5	5	4	4	4	3
Repair own equipment	5	5	5	4	4	3	3	1

TABLE 9 (continued)

	Ship							
Fleet Salvage Operations	1	2	3	4	5	6	7	8
Salvage	5	5	5	4	4	3	3	2
Rescue	5	5	5	5	4	4	4	3
Sea Detail								
Enter and leave port	5	5	5	5	5	5	5	5
Refuel and rearm underway	5	5	5	4	4	4	3	2

KEY

9	Very greatly improved	4	Slightly reduced
8	Greatly improved	3	Reduced
7	Improved	2	Greatly reduced
6	Slightly improved	1	Very greatly reduced
5	Baseline	0	No capability

Only the last characteristic is an advantage, the others result in slow and inefficient operation. The end result is a combat system that is very quickly overwhelmed in a multi-threat environment. Ship 1 was the baseline ship, and thus was rated 5 in all categories. Ship 2 has a conventional NTDS, which improves the command and control of the ship, but leaves the same fire control systems. The MK 45 gun that replaces the MK 42 on ships 2 through 8 has about half the rate of fire as the MK 42. However, in practice it was found necessary to reduce the firing rate of the MK 42 gun into the range of the MK 45 because of reliability problems. Thus the firing rate was not considered significant in evaluating the ships. Overall, ship 2 offers little change in performance from ship 1.

Ship 3 with the dual purpose MK 92 radar replacing the MK 68 and BPDMS fire control radars has a much improved capability in the AAW and SUW areas. Ships 4 through 8 have a fire control system composed of two AWG 9 radars. The AWG 9 is basicly automatic. Operator involvement is limited to monitoring the system and initiating attacks on hostile targets. The MK 92 system and the AWG 9 system both offer greatly improved performance, but in either case, if part of the system fails, there is little in the way of back-up or manual modes of operation. The same problem exists with the Automatic Detection Tracking (ADT) systems used in ship 4 through 8. When they work, ADT's have proven to be better than human operators. If ADT's fail on a ship with a very small crew, there simply

will not be enough operators to take over their functions.

The reliability and availability of the combat system should not be affected by decreases in manning. Table 8 shows sufficient time is available in the combat system skill category to do all preventive and corrective maintenance. The only exception is ship 8 where 269 hours of shore support is required per week.

A significant reduction in ASW performance takes place with ship 3. The capability of carrying nuclear weapons is forfeited. The impact of nuclear weapons aboard a ship is measured in terms of personnel much more than in terms of hardware. Two technicians and one guard are required to test or repair nuclear systems. In addition, training, drills, and paperwork are greatly increased. A ship with reduced manning simply cannot maintain the required security.

The deck watch in ship 1 requires eleven people. Ship 2 performs the same functions with six people by integrating the normal bridge equipment into one console, and adding an automatic steering device. One lookout and the Junior Officer of the Deck are also eliminated. Ship 3 through 8 have a console that was designed for two-man operation. It has a collision avoidance device and navigation aids in addition to the equipment in ship 2. Even with the improved equipment, the performance of the bridge team will decline in certain areas. For example, no amount of electronics can fully replace the three

lookouts or two signalmen normally found on a surface ship.

As mentioned in Section 2.2, the smaller ships in the study have a speed advantage over the larger ships because all the ships use the same 40,000 horsepower gas turbine propulsion plant. The CODESHIP estimation for the top speed of ship 1 is .26 knots less than the top speed of ship 8. This range of speed difference was not considered to significantly increase the performance of the small ships.

The engineering department is the foundation for the rest of the ship. Without mobility and electrical power, all the other systems are useless. As the crew size is reduced, the performance of the propulsion plant is virtually unaffected until ship 6. At this point Table 8 shows a large increase in deferred maintenance and as a result, performance will suffer. The Damage Control (DC) function is not seriously degraded until ship 6 is reached. Ship 6 has only two small damage control parties, compared with the normal three. Ship 7 has only one small damage control party, and ship 8 has virtually no DC capability, thus damage control capabilities in ships 7 and 8 would be judged unacceptable by Navy standards.

Some special functions will be difficult to accomplish for a ship with a small crew. These functions are manpower intensive and hard to automate. As an example, the smaller crews in this study cannot possibly supply a prize crew because there are simply too few ship control and propulsion operators to supply crews for two ships.

Special sea details, such as Sea and Anchor, were not considered to be a problem. In the Navy these functions are manpower intensive largely because the manpower is available, while commercial ships perform exactly the same function with very small crews.

The rankings in each function in Table 9 cannot be added to produce an overall ranking of performance. Ships 7 and 8 are unacceptable because of serious deficiencies in maintenance and damage control, yet they have only a slightly lower point total than ship 1, thus simple addition would give the wrong impression.

In general, performance is unaffected by the crew reduction in ships 1 through 5, with the exception of the loss of nuclear weapon capability.

Ship 6 is only marginally acceptable because the large amount of deferred maintenance raises doubt about the availability of equipment. Ships 7 and 8 are unacceptable for the same reason, in addition to the fact that damage control capabilities are unsatisfactory.

The reader should view Table 9 and the comments in this section with some skepticism. In order to obtain an accurate evaluation of ship performance, a full systems evaluations would have to be performed, and a manning document prepared using the DWS process for each ship in the study. This requires a number of skilled professionals and a great deal of time, thus it was beyond the scope of this thesis.

3.6 Effect of Reduced Manning on the Personnel System

The graph of crew composition versus crew size (Figure 5) presented in Section 3.1 implies a far reaching impact on the Navy's personnel system. On ship 1, which is typical of the ships now in service, personnel in low paygrades (E-1 through E-4) make up 61% of the crew. This falls to 22% on ship 8. The reduction in percentage of people at the low end of the skill scale implies an increase in the percentage at the top, and this is shown in Figure 5. The number of officers and high ranking enlisted personnel drops only slowly as the crew size is reduced, because the bulk of the reduction in crew size is at the expense of low ranking personnel.

This effect will cause problems in the training system. Currently, a large amount of training is carried out on board ship. If training billets are added to a ship with reduced manning, the advantages of reduced manning are lost. A possible solution lies in changes to the way enlisted men are detailed during their first four years of service.

Normal detailing procedures consist of:

Basic Training

Entry level training in a particular skill

Completion of obligated service at sea

A new approach consisting of the following elements will be required if low manning ships are to be effective.

Basic Training

One year or less on a ship (mess cook, deck division, ship familiarization)

One year at a shore support command (perform low skill maintenance in support of low manning ships, attend schools, and receive on the job training in rate)

Spend the remaining four year obligation at sea

In the past, personnel with certain skills have spent most of their time at sea. This system would allow their skills to be used ashore. The sailor who stays in the Navy past his four year obligation can look forward to a rotation between sea duty and the shore support activities. In the long run this should pay off with improved morale and a better retention rate, which would in turn help the rate structure problem mentioned above.

In addition to the rate problem mentioned above, the ship with a small crew will conflict with present Department of Defense (DOD) policy which allows a maximum of 70% of all enlisted personnel to be rated (paygrades E-4 through E-9). Ship 1 is well within this constraint as only 62% of the enlisted crew is rated. The FFG 7 is the first ship with a manning document which calls for more than 70% of the enlisted crew to be rated. A large number of such ships will make it impossible for the Navy to live within the 70% limit. Fortunately this constraint can be changed at the DOD level and personnel at the Bureau of Personnel expect a change within two years to accommodate the FFG 7.

Although Figure 5 doesn't show it, the ship's officers have the same training problem as the enlisted men. The ships in the lower end of the manning range have no Ensign billets. The only watchstations for officers are as one of a two-man bridge watch team and Tactical Action Officer in Combat Information Center. It is hard to imagine an Ensign filling either job. Some form of training ashore must be devised which will provide a supply of skilled officers to man these small ships.

As mentioned above, the small ships require a greater average level of skill than the larger ships. This is only partly reflected in the increased rate structure. The individuals on ships with very small crews will have to have more general training than is the present practice. This will result in an increase in cost for any given rate. The nature and cost of the extra training was beyond the scope of this thesis and was not taken into account.

3.7 Summary of Results

A brief summary of the results presented in this chapter is shown below.

Ship 1 the baseline ship, has the following features.

Crew	276	men
Displacement	4276	tons
Acquisition Cost	$72.88	million
Life Cycle Cost	$245.00	million

In comparison ship 2 has the following.

Crew	199	men
Displacement	3866	tons
Acquisition Cost	$ 72.53	million
Life Cycle Cost	$209.00	million

The reduction in crew size between ships 1 and 2 is predominantly due to the change from 1200 psi steam to gas turbine for main propulsion. Other crew reductions are as a result of reduced bridge manning, reduced gun manning, the addition of a NTDS command and control system, and second order effects. All the manning reductions are due to reduced watchstanding, either directly or indirectly. The manpower devoted to equipment maintenance is greater on ship 2 than ship 1, so equipment availability and performance should be improved. Note that acquisition cost is virtually unaffected between ship 1 and 2 because the increased cost of the more sophisticated equipment is offset by the decrease in ship size. At the same time, LCC drops sharply due to the reduction in personnel cost.

Ship 3 has the following features.

Crew	171	men
Displacement	3716	tons
Acquisition Cost	$ 74.37	million
Life Cycle Cost	$199.00	million

The reduction in crew size between ships 2 and 3 occurs because of changes to the combat system. A dual purpose fire control system replaces the two systems required for gun and missile

fire control. This results in a reduction in both operators and maintenance personnel. Other watchstanding requirements are reduced by using an integrated ship control console with navigation aids, and by eliminating the capacity to carry nuclear weapons. The number of personnel available for maintenance peaks on this ship, so equipment availability should be very good. Some combat capability is lost due to the fact that no nuclear weapons are carried, and only a four-man bridge watch is used in Condition III. Note that acquisition cost increases by two million dollars due to the more complex equipment and software required, but that a ten million dollar reduction in LCC results due to reductions in personnel cost. The FFG 7 is very close to ship 3 in terms of manning concept, thus many of the comments about ship 3 would apply to the FFG 7.

Ship 4 is considered to be the most attractive alternative. It has the following features.

Crew	139	men
Displacement	3549	tons
Acquisition Cost	$ 75.63	million
Life Cycle Cost	$189.00	million

The largest manpower savings on ship 4 are as a result of improvements to the combat system, which has automatic fire control, and automatic target detection and tracking capabilities. Ship 4 is also the first ship to transfer part of its maintenance load to shore support activities. The combat performance of this ship is good, but the automatic features leave

little in the way of back-up or casualty modes of operations. This results in greatly reduced performance in the event of equipment failure or battle damage. It is interesting that the most attractive ship also has the highest acquisition cost. This is due to the equipment changes and additions required to support the low manning. In spite of the increased acquisition cost, the LCC is reduced by ten million dollars when compared to ship 3.

Ship 5 is the first ship to transfer large amounts of maintenance to shore support activities. It has the following.

Crew	120	men
Displacement	3466	tons
Acquisition Cost	$ 75.55	million
Life Cycle Cost	$182.00	million

Because ship 5's crew size is reduced primarily by transferring functions ashore, and not by adding equipment, it's acquisition cost is less than for ship 4. The performance of this ship is reduced due to a two-man bridge watch, a one-man communications watch, and a reduced maintenance capability.

Ships 6 through 8 are similar in most respects. Ship 6 has the following characteristics.

Crew	99	men
Displacement	3368	tons
Acquisition Cost	$ 74.93	million
Life Cycle Cost	$176.00	million

Ship 8 has the characteristics shown below.

Crew	70	men
Displacement	3236	tons
Acquisition Cost	$ 74.08	million
Life Cycle Cost	$172.00	million

Ship 7 falls between ships 6 and 8 for all the values above. These three ships have small crews almost entirely because maintenance and other functions were transferred ashore. This is reflected in a reduced number of personnel devoted to maintenance on these ships, and a sharp increase cost of shore support. The performance of ship 6 is marginal due to shortcomings in equipment maintenance and damage control. Ships 7 and 8 are considered unacceptable for the same reasons. The number of hours of maintenance transferred to shore support activities indicates that not only preventive maintenance, but also corrective maintenance will be deferred. Very few personnel are available for damage control activities during Condition I, and this leads to reduced performance because damage control is difficult to automate. Automatic and installed systems have a high probability of being damaged by the very damage they are intended to counter.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary of Conclusions

This thesis has examined the impact of reduced manning aboard Naval ships. The significant conclusions which have been drawn from this analysis are as follows:

1. Manning reductions of 50% compared to the FF 1052 and 25% compared to the FFG 7 are possible in the next generation of ocean escorts using technology now available.

2. Reduction in watch stations is the key to reducing manning into the 120-160 man range from the 268 men on the FF 1052. To go below this level of manning, more reliable equipment or a change in maintenance philosophy is required. In addition, time required for support and administrative functions must be reduced.

3. The systems required to support a crew of 120 to 160 men are:

   Gas turbine or automatic steam propulsion plant

   Integrated combat system

   Integrated ship control console, and regulation changes to take advantage of it.

   Gun and missile systems which are unmanned in Condition III.

4. The speed of response necessary to control a gas turbine or a modern combat system requires a great deal of atuomation. As a result, both systems can have inherently low operational manning.

5. The ship performance is not seriously affected as the crew size is reduced from 268 to 140 men, because equipment changes offset the reduction in personnel. Ships with crews below 120 men were not satisfactory. In order for acceptable ships to be built below this range, technological improvements (many of which are under development) would be needed.

6. Reduced shipboard manning is unlikely to reduce ship acquisition cost. Reducing crew size "saves" steel and "costs" electronics. Even if crew size can be reduced with no equipment changes, the marginal cost for one man is less than .04% of the acquisition cost. Reductions in acquisition cost of ships should not be the motivation for reducing crew size.

7. The motivation to reduce crew size is to save on personnel cost, which is far the largest item in Life Cycle Cost.

8. As expected, crew cost decreases as crew size decreases, however, the average cost per man increases due to changes in rate structure and training requirements.

9. The total cost of personnel (ship and shore based) starts to level off for ships with crews of less than 120 men.

10. The productive hours per week are greater at sea than in port. This means that a person assigned to a ship will accomplish more than the same person assigned to a shore support activity, <u>if</u> the ship can use his services on a full time basis.

11. From the standpoint of performance, it is better to

have one technician aboard ship and available 100% of the time, than to have two technicians available the 50% of the time the ship is in port.

12. The tendency to "overman" must be avoided. This requires equipment that will gain the operators confidence, and operators that understand and support the motivation to reduce manning.

4.2 Recommendations for Further Study

Reduced shipboard manning is a subject which affects almost all aspects of ship design. Some areas where further research is desirable include:

1. The crew size and composition used on the ships in this thesis should be verified, using the Design Work Study Method.

2. Further work is required to validate the ship performance results obtained in this thesis.

3. The experience gained from the FFG 7 and DD 963 must be studied and applied before the next generation of ships with still smaller crews can be constructed.

4. Concepts which have been proposed to reduce shipboard manning, such as the application of minicomputers to shipboard functions, automatic food service, disposable clothes, and others, must be evaluated on a case-by-case basis to determine whether their high first cost and complexity are justified by long range savings.

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APPENDIX A

SAMPLE CODESHIP INPUT AND OUTPUT

Input and output data for the FF 1052 as first constructed is presented here. The output is compared with the characteristics of the actual FF 1052 in Table A-1.

TABLE A-1

COMPARISON OF FF 1052 AS BUILT AND AS PREDICTED

	As Built	As Predicted	Actual/Predicted
Length	415.0 ft.	416.4 ft.	.996
Beam	46.6	46.7	.998
Draft	15.0	15.0	1.000
Hull depth	28.7	29.5	.973
Displacement light	3011.0 tons	2999.7 tons	1.004
Full load displacement	3934.0	4031.0	.976
Volume	471.0 K ft^3	436.0 K ft^3	1.080

SHIP SPECIFICATIONS

SUS SPD		BOILSIZE	17500.00	SPECL WT	0.00
END SPD	20.00	NUMBOILS	2.00		0.00
RANGE		ENG SIZE	35000.00	SPECLGFM	0.00
SHIPTYPE	1.00	NUM ENGS	1.00		0.00
HULL CP	0.58	ENG LOC	1.00		0.00
HULL CX	0.81	GEARTYPE	1.00		0.00
HULL L/B	8.91	SHFTTYPE	1.00		0.00
HULL B/H	3.11	NUMSHFTS	1.00		0.00
BSTN/B	0.85	DOME LOC	0.00		0.00
HULLKOTE	1.00		0.00		0.00
NUM COMP	3.00		0.00	YEARCOST	1974.00
HULL MAT	2.00		0.00	NUM PROD	50.00
PILOTMAT	2.00		0.00	INFLATN	7.00
SUPVPCT	22.00		0.00	LAB RATE	4.98
HULLTYPE	1.00	OFFACCOM	22.00	OVERHEAD	92.00
HNGR HT	0.00	CPOACCOM	22.00	DE LABOR	5.67
L MIN	0.00	ENLACCOM	240.00	DEOVRHED	92.00
L MAX	900.00	SHIPDAYS	45.00	PROFIT	10.00
B MIN	0.00	ELECT KW	3000.00	PLANS F	2000000.00
B MAX	90.00	TRPACCOM	0.00	TST IN L	15000000.00
H MIN	0.00	TRPDAYS	0.00	TST IN F	100000.00
H MAX	90.00		0.00	FUTRE L	0.00
	0.00		0.00	FUTURE F	0.00
	0.00		0.00	STCKSP L	3500000.00
PP TYPE	2.00	DCMRGPCT	0.00	STCKSP F	0.00

HULLTYPE	STANDARD	POWRPLNT	HIPRSTEM	HULL MAT	HITENSTL
SHIPTYPE	COMBATNT	ENG LOC	AMIDSHIP	PILOTMAT	ALUMINUM
		GEARTYPE	LCKDTRAN	HULLKOTE	VINLRES
		SHFTTYPE	HOLLOW		

PAYLOAD SPECIFICATIONS

QNTY	ITEM	QNTY	ITEM	QNTY	ITEM	QNTY	ITEM	QNTY	ITEM
1.00	1	1.00	136	12.00	295				
1.00	12	1.00	150	162.00	345				
1.00	20	1.00	186	1.00	361				
1.00	42	1.00	188	1.00	372				
1.00	63	1.00	189	1.00	472				
1.00	67	2.00	206	1.00	473				
1.00	75	2.00	209						
100.00	80	1.00	231						
1.00	81	1.00	247						
1.00	96	1.00	256						
1.00	104	1.00	267						
1.00	115	600.00	275						
1.00	131	8.00	287						
1.00	134	22.00	293						

SUMMARY OF RESULTS

MAX SPD	0.00	LITEWATE	2999.69	YR COSTS	1974.00
MXSPDRNG	0.00	DCMARGIN	0.00	NUM PROD	50.00
ACTSUSPD		VAR LOAD	931.55	ENDCOSTP	133.39
SUSPDRNG	0.00	DOMEWATR	100.00	ENDFRSTF	78.58
ACTNDSPD	20.00	TOTAL WT	4031.24	ENDCOSTF	67.69
ACTNDRNG			0.00	ENDCOSTA	69.00
REQSUSPP	31250.69	PAYLD WT	771.87		0.00
ACTSUSPP	35000.00	PAYLDGFM	0.00	REQDKFT3	437.72
REQENDPP	0.00	SHIPCREW	284.00	AVALKFT3	436.33
ACTENDPP	0.00	NUM TRPS	0.00	AVL/REQV	99.68
	0.00	ELECT KW	3000.00	SUP/HULV	22.00
HULLNGTH	416.41	HULL L/B	8.91		0.00
HULLBEAM	46.74	HULL B/H	3.11	CG HT FT	15.87
HULDRAFT	15.03	PRISCOEF	0.58	METACNTR	7.85
FREEBORD	14.44	MIDXCOEF	0.81	GM/B PCT	16.79
HULDEPTH	29.47		0.00		0.00
FLTDEPTH	29.47	MX WEL B	14.74	RQDHNGRA	0.00
	0.00	MX WEL L	333.13	MX HNGRA	0.00
REQSUPV	43682.51	RQDWEL A	0.00	RQDFLTA	0.00
AVALSUPV	78682.00	MX WEL A	2454.46	MX FLT A	0.00

END COST INCREMENTS

	PROTO K$	FOLLOW K$		PROTO K$	FOLLOW K$
CONST PLANS	14870.	2000.	STOK SPARES	3500.	0.
CHANGE ORDERS	6347.	3340.	DEVELOPMENT	10000.	1000.
SHP SYS ENG	9205.	1965.	LECTRN GROWTH	1194.	1194.
ESCALATION	19310.	10608.	ORDNCE GROWTH	2856.	2856.
TEST&INSTRUM	15000.	100.	TOT INCREMENT	82283.	23662.
FUT CHAR CHG	0.	0.	END COST	133392.	67687.

ITERATION HISTORY

VOL IT	WT ITS	TOTWT TONS	CALWT TONS	FREBRD FEET	VOLRAT PCT	B/H	GM FEET	GM/B PCT
1	2.	3846.8		9.66	77.72	3.11	9.64	20.96
2	2.	4025.6		14.14	98.46	3.11	7.98	17.07
3	1.	4025.6		14.44	99.68	3.11	7.85	16.79

DETAILED RESULTS

COMP	NAME	WEIGHT TONS	WEIGHT PCT	VOLUME KFT3	VOLUME PCT	CTBAS K$	CTBAS PCT	MOMENT KFTTON
11	BASCHULL	708.0	17.6	0.0	0.0	3028.	5.9	11.3
12	SEC HULL	366.4	9.1	0.0	0.0	2023.	4.0	6.4
10	HULL GRP	1074.4	26.7	0.0	0.0	5051.	9.9	17.6
21	BOILERS	332.5	8.2	46.0	10.5	4426.	8.7	4.9
22	ENGINES	178.1	4.4	43.9	10.0	2665.	5.2	2.8
23	TRANSMIS	60.4	1.5	5.0	1.1	488.	1.0	0.4
24	ELECTRIC	120.0	3.0	15.6	3.6	3085.	6.0	2.4
25	PROPELRS	8.5	0.2	0.0	0.0	0.	0.0	0.0
26	SHP FUEL	684.0	17.0	26.0	5.9	0.	0.0	5.2
27	FUEL SYS	27.4	0.7	0.0	0.0	530.	1.0	0.4
20	POWR GRP	1410.9	35.0	136.5	31.2	11194.	21.9	16.2
31	PILTHOUS	4.2	0.1	1.7	0.4	33.	0.1	0.2
32	NAV+COMM	12.1	0.3	1.4	0.3	685.	1.3	0.4
33	MOOR+RIG	71.6	1.8	28.1	6.4	694.	1.4	1.9
34	STER+TRM	82.0	2.0	24.5	5.6	1129.	2.2	1.2
35	BALLAST	0.0	0.0	0.0	0.0	0.	0.0	0.0
30	SHCONGRP	169.9	4.2	55.8	12.7	2541.	5.0	3.6
41	PERSONEL	20.9	0.5	0.0	0.0	0.	0.0	0.6
42	P EFECTS	10.9	0.3	0.0	0.0	0.	0.0	0.3
43	P STORES	102.2	2.5	12.4	2.3	0.	0.0	1.2
44	NCLOSURS	142.0	3.5	98.3	22.5	2133.	4.2	4.0
45	FURNISHG	73.8	1.8	0.0	0.0	1274.	2.5	2.0
46	H,V,PLUM	87.3	2.2	9.5	2.2	2987.	5.8	2.3
47	LIGHTING	14.9	0.4	0.0	0.0	0.	0.0	0.4
48	P SAFETY	12.4	0.3	0.0	0.0	73.	0.1	0.5
40	ACOM GRP	464.5	11.5	120.2	27.5	6466.	12.7	11.2
51	BALISTIC	0.0	0.0	0.0	0.0	0.	0.0	0.0
52	TORPEDO	0.0	0.0	0.0	0.0	0.	0.0	0.0
53	BLAST	0.0	0.0	0.0	0.0	0.	0.0	0.0
54	FIREPROT	31.5	0.8	3.8	0.9	558.	1.1	0.7
55	DEGAUSS	8.2	0.2	0.0	0.0	206.	0.4	0.2
50	SHSAFGRP	39.7	1.0	3.8	0.9	764.	1.5	0.9
61	LECTRONS	305.2	7.6	43.9	10.0	10357.	20.3	1.7
62	WEAPONS	394.7	9.8	42.5	9.7	12683.	24.8	10.5
63	CARGO	55.7	1.4	2.2	0.5	1832.	3.6	1.6
64	MISCEL	16.2	0.4	0.0	0.0	220.	0.4	0.6
65	SPECIAL	0.0	0.0	0.0	0.0	0.	0.0	0.0
60	PAYLDGRP	771.9	19.1	88.6	20.2	25092.	49.1	14.4
	TOTAL	4031.2	100.0	437.7	100.0	51110.	100.0	64.0

DETAIL COSTS WITHOUT LEARNING

COMP	NAME	TOTAL HOURS THOUS	TOTAL LABOR K$	TOTAL MATERIAL K$	PROFIT COST K$	BASIC CONST K$	GFM COST K$	TOTAL BASIC K$
11	BASCHULL	226.	2179.	573.	275.	3028.	0.	3028.
12	SEC HULL	153.	1478.	361.	184.	2023.	0.	2023.
10	HULL GRP	380.	3657.	935.	459.	5051.	0.	5051.
21	BOILERS	173.	1672.	2352.	402.	4426.	0.	4426.
22	ENGINES	77.	743.	1680.	242.	2665.	0.	2665.
23	TRANSMIS	16.	152.	292.	44.	488.	0.	488.
24	ELECTRIC	129.	1243.	1562.	280.	3085.	0.	3085.
25	PROPELRS	0.	0.	0.	0.	0.	0.	0.
26	SHP FUEL	0.	0.	0.	0.	0.	0.	0.
27	FUEL SYS	34.	332.	150.	48.	530.	0.	530.
20	POWR GRP	430.	4141.	6035.	1018.	11194.	0.	11194.
31	PILTHOUS	2.	21.	9.	3.	33.	0.	33.
32	NAV+COMM	16.	152.	471.	62.	685.	0.	685.
33	MOOR+RIG	33.	319.	312.	63.	694.	0.	694.
34	STER+TRM	62.	602.	425.	103.	1129.	0.	1129.
35	BALLAST	0.	0.	0.	0.	0.	0.	0.
30	SHCONGRP	114.	1094.	1216.	231.	2541.	0.	2541.
41	PERSONEL	0.	0.	0.	0.	0.	0.	0.
42	P EFECTS	0.	0.	0.	0.	0.	0.	0.
43	P STORES	0.	0.	0.	0.	0.	0.	0.
44	NCLOSURS	143.	1380.	559.	194.	2133.	0.	2133.
45	FURNISHG	62.	599.	559.	116.	1274.	0.	1274.
46	H,V,PLUM	188.	1812.	904.	272.	2987.	0.	2987.
47	LIGHTING	0.	0.	0.	0.	0.	0.	0.
48	P SAFETY	1.	12.	54.	7.	73.	0.	73.
40	ACOM GRP	395.	3803.	2076.	588.	6466.	0.	6466.
51	BALISTIC	0.	0.	0.	0.	0.	0.	0.
52	TORPEDO	0.	0.	0.	0.	0.	0.	0.
53	BLAST	0.	0.	0.	0.	0.	0.	0.
54	FIREPROT	30.	286.	221.	51.	558.	0.	558.
55	DEGAUSS	7.	71.	116.	19.	206.	0.	206.
50	SHSAFGRP	37.	357.	338.	69.	764.	0.	764.
61	LECTRONS	342.	3291.	1404.	469.	5164.	5193.	10357.
62	WEAPONS	198.	1911.	964.	288.	3163.	9521.	12683.
63	CARGO	39.	375.	1290.	167.	1832.	0.	1832.
64	MISCEL	9.	84.	0.	8.	93.	128.	220.
65	SPECIAL	0.	0.	0.	0.	0.	0.	0.
60	PAYLDGRP	588.	5661.	3659.	932.	10252.	14841.	25092.
	TOTAL	1942.	18714.	14258.	3297.	36269.	14841.	51110.

OBJECT CODE= 82128 BYTES,ARRAY AREA= 32724 BYTES,

NUMBER OF ERRORS= 0, NUMBER OF WARNINGS=

1.77 SEC,EXECUTION TIME= 3.44 SEC, WATFIV

APPENDIX B

IN PORT WATCHSTANDERS

When a ship is in port certain stations are manned to provide security against intruders, fire, and flooding. The watchstations shown in Table B-1 were assumed to be manned for the purpose of calculating in port workload.

TABLE B-1

IN PORT WATCHSTANDERS

Ship Number	1	2	3	4	5	6	7	8
Command Duty Officer	1	1	1	1	1	1	1	1
Asst. Command Duty Officer	1							
Quarter Deck Watch	3	3	3	3	3	3	3	3
Asst. Quarter Deck Watch	3	3						
Messenger (Quarter Deck)	3	3	3	3	3			
Below Deck Security	3	3	3	3	3	3	3	3
Machinery Watch	3	3	3					
Asst. Machinery Watch	3							
Helo Detachment	1	1	1	1	1	1	1	1
Nonwatchstanders	12	8	8	10	7	6	5	2

APPENDIX C

SHIP CREW COMPOSITION

Appendix C presents the crews assumed for the ships in this study according to rating and paygrade. Every ship in the study was assumed to carry a 14 man helicopter detachment consisting of three officers, one chief petty officer, and ten enlisted personnel. These personnel are not included in the tables of this appendix.

The ships officers are shown in Table C-1, and the enlisted personnel are presented in Tables C-2 through C-9. For those unfamiliar with the abbreviations used in the Navy's personnel system, definitions are provided at the end of Appendix C.

TABLE C-1

OFFICER COMPOSITION

Ship	Commander	Lieutenant commander	Lieutenant	Lieutenant junior grade	Ensign
1	1	1	3	7	2
2	1	1	4	3	1
3	1	1	4	3	1
4	1	1	3	4	0
5	1	1	3	4	0
6	1	1	3	4	0
7	1	1	3	3	0
8	1	1	3	3	0

TABLE C-2

SHIP 1 ENLISTED CREW

Rating	Paygrade							
	E-9	8	7	6	5	4	3	2	Total
3-M	1								1
YN/PN			1	1		3			5
HM			1				1		2
QM			1		1	2			4
OS			1	2	5	6	7		21
PC						1			1
RM			1	1	3	3	4		12
SM				1	2	3			6
BM/SN			1	1	1	3	24	6	36
ST		1		3	3	6	4		17
FT			1	1	1	4	3		10
GM			1	1	4	5	5		16
TM					1				1
ET			1		3	2	1		7
IC				1	1	2	1		5
MM			1	3	7	10	3		24
BT	1		1	2	3	3	3		13
EM			1		2	3	1		7
EN				1	1	1			3
HT				1	2	4	1		8
FN							9	5	14
MR					1				1
SK			1	1	1	1	1		5

SHIP 1 ENLISTED CREW (continued)

Rating	Paygrade								
	E-9	8	7	6	5	4	3	2	Total
SH				1	1	2	2		6
DK				1					1
MS			1	2	1	2	1		7
Messmen								9	9
Steward				1	1	1	3		6
Total	2	1	14	24	45	67	74	20	247

TABLE C-3

SHIP 2 ENLISTED CREW

Rating	Paygrade								
	E-9	8	7	6	5	4	3	2	Total
YN/PN			1	1	1	1			4
HM				1					1
SC			1	1	2	3	6	3	16
OS			1	2	4	7	4		18
RM			1	1	3	3	3		11
BM	1			1	1	1	7	6	17
ST		1		3	3	3	3		13
FT			1	1	2	3	1		8
GM			1	1	3	5	1		11
TM						1			1
ET			1		2	2	1		6
EW			1	1	1	1			4
DS				1	3	1			5
IC				1	1	1			3
EM			1	1	2	2	3	2	11
EN		1	1	2	3	3	3	1	14
HT				1	1	1	1		4
MR					1				1
SK			1	1	2	1			5
DK					1				1

SHIP 2 ENLISTED CREW (continued)

Rating	Paygrade								
	E-9	8	7	6	5	4	3	2	Total
MS			1	1	3	1			6
Messmen							5	4	9
SH				1	1	1	3		6
Total	1	2	12	22	40	41	41	16	175

TABLE C-4

SHIP 3 ENLISTED CREW

Rating	Paygrade								
	E-9	8	7	6	5	4	3	2	Total
YN/PN			1	1	1	1			4
HM				1					1
SC			1	1	2	3	4		11
OS			1	2	3	2	4		12
RM			1	1	1	3	1		7
BM	1			1	1	1	11		15
ST		1		2	3	2	2		10
FT			1	2	3	2	2		10
GM			1	1	2	1	1		6
TM						1			1
ET			1		3	1	1		6
EW				1	1	1			3
DS				1	2	1			4
IC				1	1	1			3
EM			1	1	2	2	3	2	11
EN		1	1	2	3	3	3	1	14
HT				1	1	1	1		4
MR					1				1
SK			1	1	2	1			5
DK					1				1

SHIP 3 ENLISTED CREW (continued)

Rating	Paygrade								
	E-9	8	7	6	5	4	3	2	Total
MS			1	1	3	1			6
Messmen							3	3	6
SH				1	1	1	3		6
Total	1	2	11	22	37	29	39	6	147

TABLE C-5

SHIP 4 ENLISTED CREW

Rating	Paygrade								
	E-9	8	7	6	5	4	3	2	Total
YN/PN			1	1		1			3
HM				1					1
SC			1	1	2	2	2		8
OS			1	1	2	1	2		7
RM			1	1	1	3	1		7
BM	1			1	1	1	6		10
ST		1		2	1	2	1		7
FT			1	2	1	2	1		7
GM			1	1	1	1			4
TM						1			1
ET			1		3	1	1		6
EW				1	1	1			3
DS				1	2	1			4
IC				1		1			2
EM			1	1	2	2	2	1	9
EN		1	1	2	3	3	2		12
HT				1		1	1		3
MR					1				1
SK			1	1	1	1			4
DK					1				1

SHIP 4 ENLISTED CREW (continued)

Rating	Paygrade							
	E-9	8	7	6	5	4	3	2	Total
MS			1	1	2	1			5
Messmen							4	3	7
SH				1		1	2		4
Total	1	2	11	21	25	27	25	4	116

TABLE C-6

SHIP 5 ENLISTED CREW

Rating	E-9	8	7	6	5	4	3	2	Total
				Paygrade					
YN			1			1			2
HM				1					1
SC			1	1	2	1			5
OS			1	1	1	2	2		7
RM			1	1	1	2			5
BM			1	1		1	6		9
ST		1		2	1	2			6
FT			1	2	1	1	1		6
GM			1	1	1	1			4
TM						1			1
ET			1		2	1			4
EW				1	1	1			3
DS				1	1	1			3
IC				1		1			2
EM			1	1	2	2	1	1	8
EN		1	1	2	3	2	2		11
HT				1		1	1		3
MR					1				1
SK			1	1		1			3
MS			1	1	1	1			4

SHIP 5 ENLISTED CREW (continued)

Rating	Paygrade								
	E-9	8	7	6	5	4	3	2	Total
Messmen							6		6
SH				1		1	1		3
Total	0	2	12	20	18	24	20	1	97

TABLE C-7

SHIP 6 ENLISTED CREW

Rating	Paygrade								
	E-9	8	7	6	5	4	3	2	Total
YN			1			1			2
HM				1					1
SC			1	1	2				4
OS			1	1	1	1			4
RM			1	1	1	2			5
BM			1	1		1	3		6
ST		1		2	1	1			5
FT			1	2	1	1			5
GM			1	1	1	1			4
ET			1		2				3
EW				1	1	1			3
DS				1	1	1			3
IC				1					1
EM			1	1	2	1	1		6
EN		1	1	2	2	2	1		9
HT				1		1			2
SK			1		1				2
MS			1		1		6		8
SH				1		1	1		3
Total	0	2	12	18	16	16	12	0	76

TABLE C -8

SHIP 7 ENLISTED CREW

Rating	Paygrade								
	E-9	8	7	6	5	4	3	2	Total
YN			1			1			2
HM				1					1
SC			1	1	2				4
OS			1	1	1				3
RM			1	1		2			4
BM				1		1	3		5
ST		1		2	1				4
FT			1	2	1	1			5
GM			1	1	1	1			4
ET			1		2				3
EW				1	1	1			3
DS				1	1	1			3
IC				1					1
EM			1	1	2	1	1		6
EN		1	1	2	2	2			8
HT				1					1
SK			1			1			2
MS				1	1		5		7
Total	0	2	10	17	16	12	9	0	66

TABLE C-9

SHIP 8 ENLISTED CREW

Rating	Paygrade								
	E-9	8	7	6	5	4	3	2	Total
YN				1					1
HM				1					1
SC			1	1	2				4
OS			1	1	1				3
RM			1			2			3
BM				1			3		4
ST			1	1	1				3
FT			1	2		1			4
GM				2					2
ET					2				2
EW				1	1	1			3
DS				1		1			2
IC				1					1
EM			1	1	1	1			4
EN				2		2			4
HT					1				1
SK				1					1
MS				1	1		3		5
Total	0	0	6	18	10	8	6	0	48

ABBREVIATIONS USED IN APPENDIX C

BM/SN	Boatswain's Mate
BT	Boiler Technician
DK	Pay Records Administrator
DS	Data Systems Technician
EM	Electrician
EN	Engineman
ET	Electronics Technician
EW	Electronic Warfare Technician
FN	Fireman
FT	Fire Control Technician
GM	Gun Ordnance Technician
HM	Medical Technician
HT	Hull Technician
IC	Interior Communications Technician
3-M	Maintenance Manager
MM	Propulsion Machinery Operator
MR	Machinery Repairman
MS	Ship's Cook
OS	Operations Specialist
PC	Postal Clerk
PN	Personnelman
QM	Quartermaster
RM	Communications Technician

ABBREVIATIONS USED IN APPENDIX C
(continued)

SH	Ship's Service
SK	Supply Accountant
SM	Visual Communications Technician
ST	Sonar Technician
TM	Torpedo Technician
YN	Administrative Clerk

APPENDIX D

DETAILED WORKLOAD ACCORDING TO SKILL CATEGORY

Appendix D presents the detailed analysis of the hours required per week for each manning function in each skill category. The values for ship 1 are the same as for the modified FF 1052. The change in hours required in each function for each ship was calculated using the methods in Section 2.1. The hours available were based on the Navy Standard Work Week. The differences between total hours required and hours available in each skill category are presented in Table 8.

TABLE D-1

COMBAT SYSTEMS
REQUIRED HOURS OF LABOR/WEEK

Ship	Maintenance	Utility	Administration	Facilities Maintenance	Watch	Required Total	Available
1	443.6	416.23	114.55	178.27	2352	3504.65	3524.5
2	646.0	55.00	85.00	123.00	1848	2758.00	3119.0
3	580.0	55.00	85.00	107.00	1176	2004.00	2512.0
4	511.0	55.00	85.00	91.00	504	1247.00	1855.0
5	511.0	55.00	85.00	81.00	504	1237.00	1605.0
6	511.0	55.00	85.00	73.00	504	1229.00	1355.0
7	511.0	55.00	85.00	71.00	504	1227.00	1305.0
8	511.0	55.00	85.00	63.00	504	1219.00	955.0

TABLE D-2

OPERATIONS
REQUIRED HOURS OF LABOR/WEEK

Ship	Maintenance	Utility	Administration	Facilities Maintenance	Watch	Required Total	Available
1	102.35	222.13	85.95	77.07	1680	2167.5	2167.5
2	78.00	42.00	85.00	69.00	1512	1787.0	1915.0
3	78.00	42.00	85.00	49.00	1008	1263.0	1260.0
4	78.00	42.00	85.00	39.00	672	917.0	907.0
5	78.00	42.00	85.00	35.00	504	745.0	755.0
6	78.00	42.00	85.00	29.00	336	571.0	553.0
7	78.00	42.00	85.00	25.00	336	567.0	453.0
8	78.00	42.00	85.00	25.00	336	567.0	403.0

TABLE D-3

DECK
REQUIRED HOURS OF LABOR/WEEK

Ship	Maintenance	Utility	Administration	Facilities Maintenance	Watch	Required Total	Available
1	105.03	109.43	42.50	372.34	1624	2253.3	2300.25
2	105.00	109.00	42.00	332.00	168	757.0	901.00
3	105.00	109.00	42.00	322.00	0	571.0	750.00
4	105.00	109.00	42.00	311.00	0	567.0	500.00
5	105.00	109.00	42.00	302.00	0	559.0	450.00
6	105.00	109.00	42.00	293.00	0	549.0	300.00
7	105.00	109.00	42.00	290.00	0	546.0	250.00
8	105.00	109.00	42.00	287.00	0	546.0	250.00

TABLE D-4

SHIP CONTROL
REQUIRED HOURS OF LABOR/WEEK

Ship	Maintenance	Utility	Administration	Facilities Maintenance	Watch	Required Total	Available
1	6.96	52.21	62.11	29.97	504	655.25	655.25
2	22.00	42.00	31.00	36.00	840	972.00	1058.00
3	22.00	42.00	31.00	31.00	504	631.00	705.00
4	22.00	42.00	31.00	25.00	336	457.00	503.00
5	22.00	42.00	31.00	21.00	168	285.00	301.00
6	22.00	42.00	31.00	18.00	168	282.00	251.00
7	22.00	42.00	31.00	16.00	168	280.00	251.00
8	22.00	42.00	31.00	16.00	168	280.00	251.00

TABLE D-5

ENGINEERING
REQUIRED HOURS OF LABOR/WEEK

Ship	Maintenance	Utility	Administration	Facilities Maintenance	Watch	Required Total	Available
1	691.67	579.74	220.98	326.02	235.2	4170.5	4174.5
2	695.00	127.00	54.00	222.00	560.0	1658.0	1672.0
3	685.00	127.00	54.00	193.00	560.0	1619.0	1672.0
4	685.00	127.00	54.00	157.00	504.0	1527.0	1672.0
5	685.00	127.00	54.00	133.00	504.0	1503.0	1305.0
6	685.00	127.00	54.00	110.00	448.0	1424.0	970.0
7	685.00	127.00	54.00	94.00	336.0	1296.0	853.0
8	685.00	127.00	54.00	79.00	168.0	1034.0	502.0

TABLE D-6

SUPPORT
REQUIRED HOURS OF LABOR/WEEK

Ship	Maintenance	Utility	Administration	Facilities Maintenance	Watch	Required Total	Available
1	9.16	975.84	596.4	393.8	56	2042.2	2167.3
2	9.00	707.00	569.0	285.0	0	1570.0	1600.0
3	9.00	614.00	546.0	248.0	0	1417.0	1450.0
4	9.00	498.00	494.0	201.0	0	1202.0	1250.0
5	9.00	424.00	476.0	171.0	0	1091.0	950.0
6	9.00	350.00	458.0	140.0	0	958.0	850.0
7	9.00	300.00	445.0	121.0	0	875.0	600.0
8	9.00	252.00	431.0	100.0	0	792.0	400.0